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December 3, 4 and 5, 1957

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1958

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ACKNOWLEDGMENTS

It is the desire of the Executive Committee to take this opportunity to thank the Officials of the College of Agriculture of the University of Florida for making the requisite facilities in Dan McCarty Hall available for the 1957 Annual Meetings of the Society. They proved eminently satisfactory from every standpoint and contributed greatly to the success of the various programs that are faithfully reported in this volume.

Likewise the Committee would express its real appreciation to Provost Willard M. Fifield for his inimitably capable handling of the Toastmaster's Post at the banquet and to Mrs. Marjorie Hamilton for the fine banquet and the excellent manner in which it was served; also to the members of the local committee on arrangements appointed by President McCloud, under the chairmanship of Dr. W. K. Robertson, who took such good care of the many details both in preparation for the meetings and during their progress.

The particular thanks of the entire membership of the Society are extended to Dr. Firman E. Bear, retired head of the Soils Department at Rutgers University and Editor-in-Chief of Soil Science for coming all the way from New Jersey with his charming wife to meet with us and to deliver a most interesting and timely address, entitled "All Flesh is Grass," at the time of the banquet. We are also grateful to Dr. Bear for his gracious acceptance of an honorary lifetime membership in the Society to which he was nominated and unanimously elected in the course of the business meeting. In initiating Dr. Bear's membership at that time, recognition also was given to that of Dean Emeritus, Dr. H. H. Hume who had been chosen during the period between the meetings but in time for the announcement of it to appear in Proceedings Volume 16 (1956), which volume was formally dedicated to him and to the remarkably fine service he has rendered to Florida Agriculture thru the years.

Finally, the Executive Committee expresses its appreciation to those who took an active part in the program of the Seventeenth Annual Meeting and particularly thanks them for their promptness in making their manuscripts available for publication in a manner that greatly expedited the press work on Proceedings Volume 17 (1957) and its availability for mailing to each member.

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FIRMAN E. BEAR

Honorary Lifetime Member
1957

FIRMAN E. BEAR

Dr. Bear was born at Germantown, Ohio, May 21, 1884. He attended Ohio State College, earning the Bachelor of Science degree in 1908. His major interest was Agricultural Chemistry. He continued his studies at Ohio State while serving simultaneously as an instructor in Soils and was awarded the Master of Science degree in 1910. The Ph.D. degree was obtained from the University of Wisconsin in 1917 where he majored in Bacteriology and minored in Biological Chemistry. An honorary D.Sc. degree was awarded by Rutgers University in 1954.

After beginning his teaching career at Ohio State University, Dr. Bear served as Professor and Chairman of the Soils Departments at West Virginia, Ohio State and Rutgers Universities. Interspersing his institutional assignments, he was director of agricultural research for the American Cyanamid Company for ten years and Science Editor for Country Home magazine for two years. Following retirement from Rutgers in 1954, he is Editor-in-Chief of Soil Science.

Dr. Bear is the author of two books on soils and fertilizers and is joint author of three other books. The best known of his textbooks, *Soils and Fertilizers,* is in its fourth edition. He has published numerous research bulletins and journal papers on soil-plant science. In 1955, he edited a book on "Chemistry of the Soil," a monograph of the American Chemical Society. For the past 15 years a large part of Dr. Bear's time was devoted to the study of trace elements and a final review of this work can be found in the Journal of Agricultural and Food Chemistry, 2:244-249, 1954.

Dr. Bear has served on the National Science Council and the Council of the American Chemical Society. He was elected a Fellow in the American Society of Agronomy and the Soil Conservation Society of America and has served as president of both societies. He was also president of the Soil Science Society of America and is now a member of the Secretary of Agriculture's Advisory Committee on Soil Conservation.

In recognition of Dr. Bear's numerous contributions in the field of Soil Science, the greatest of these being in the training and supervision of many outstanding graduate students, we are proud to dedicate Volume 17 of the Proceedings of the Soil and Crop Science Society of Florida.

All Flesh Is Grass

FIRMAN E. BEAR

In fulfillment of the prophecy, Nebuchadnezzar "was driven from men and did eat grass as oxen, and his body was wet with the dew of heaven, till his hairs were grown like eagles' feathers and his nails like birds' claws."

We need more such grass. And soil is the starting point in producing it. For grass and all the other plants require soil-derived mineral nutrients in constructing carbohydrates, oils, proteins, vitamins, and the great variety of additional organic compounds contained in them out of atmospheric gases and the water that falls as rain. Plants are producers of organic matter. Man is a consumer of it.

Most of the mineral nutrients required by plants have known value to man as well. But one of them—boron—does not. And crop plants usually contain traces of iodine, fluorine and cobalt—elements of no known value to the plants themselves but essential to the well-being of man. They also contain considerably amounts of silicon, aluminum, and titanium and lesser amounts of a great variety of other mineral elements of no known value either to the plants themselves or to man.

By and large, the composition of the air and of the water that falls as rain out in the open country are essentially the same the Earth over. The primary variables that affect the composition of any given species and variety of plant are the soil on which it grows, the climate in which it is located, and the amount of daylight at its disposal.

This paper has to do with soils—the great differences that exist in them the Earth over and how these differences may affect the mineral and organic qualities of plants in relation to the food needs of man. I prefer to introduce the subject by asking a series of questions:

Should the nature of the soil be considered in choosing a location in which to bring up a family? Does it make any difference whether the corn and cabbage, oats and oranges, rye and rice, turnips and tomatoes, and the many other grains, fruits, and vegetables we eat and the water and wine we drink came from soils that were derived from granite, limestone, sandstone, or shale, or even from beach sand or peat?

Do the chemically quite-different gray, brown, black, yellow, and red soils of the Earth produce widely different plant products that are capable of putting their respective marks on mankind: If so, are these differences in nutritional effects due to variations in the organic or the inorganic qualities of the plant produce, or to both?

Is it important to man whether farmers in the acid-soil regions of the Earth lime the land on which food crops are to be grown? Does it make any difference to consumers of plant produce whether the supplies of nitrogen and mineral nutrients in soils are renewed by applications of chemical fertilizers rather than by the use of legume cover-crops and manures?

What are the mineral requirements of man as to the major, secondary, and trace elements? To what extent does our present hit-and-miss system of meeting these requirements satisfy these needs?

When acre yields of crops are raised to high levels does this result in a lowering of their mineral-nutrition value? If the mineral content of food could be doubled without disturbing the ratios among the several mineral elements, would this result in injury to man?

Would anything be gained by substituting seasalt, with its great variety of mineral elements, for the nearly pure sodium chloride that is now being used for seasoning purposes? Or, would it be better to make supplemental use of a synthetic salt mixture comparable to that of the ash of the edible portions of plants grown on soils of high repute for the excellence of the mineral quality as evidenced by livestock, as in the Bluegrass Region of Kentucky.

If extra minerals were supplied in a supplemental salt mixture, should this be made up of organic or inorganic salts? Should missing mineral elements needed by man but not by plants be supplied by way of the soil and crop rather than as a mineral supplement to the salt that is being consumed?

Is there any evidence that people from the drier regions of the Earth are physically or mentally superior to their counterparts whose food is derived from the badly leached soils of the high-rainfall regions of the Earth. Would it be desirable to encourage greater interchange of foodstuffs among the peoples of the several soil and climatic regions of the Earth?

If the mineral or organic quality of the plant produce of any given region needs to be improved, can this best be done by applying mineral amendments to the soil, mixing them with the table-salt, breeding nutritionally-better food plants of the same species, growing other species of food plants, or by making use of supplemental foods—natural or synthetic—that contain more of the missing constituents? Can a purely plant diet be made equally as nutritious for man as one that is supplemented by the edible products of animals?

These questions are not raised with the thought of dealing directly with them, since considerable doubt exists in the minds of most men as to what the answers to many of them should be. The thought is rather that, with these questions in mind, we should be in a much better position to think of the soil in relation to meeting the nutritional needs of man.

What is soil? At the moment it will be sufficient to say that it consists of rock residues mixed with rotting remnants of plant and animal life. The rocks from which the soils were derived may have been the original lavas, the somewhat later granite types, or the sedimentary types that were derived from the original rocks, as in the case of limestones, sandstones, and shales. But the climatic and biologic factors involved in the breakdown of rocks into soil must be considered. These may have been those of the desert, the grass-covered plains and prairies, the high-rainfall tree-covered temperate regions, or the still higher-rainfall and more densely-forested Tropics.

The soils of the several regions of the Earth differ markedly in their physical and chemical makeup. These variations greatly modify the nature and composition, both organic and inorganic, of the

plants growing on them. Extremes of plants serving as sources of food might be represented by the cactus and the banana.

To simplify the presentation it seems desirable to divide the agricultural soils of the Earth into four large groups. These are based primarily on long-time effects of climate and the associated vegetation on the breakdown of the rocks from which the soils were formed. Climate and vegetation rather than the kind of rock tend finally to determine the nature of the soil.

These four groups are the gray-red soils of the arid regions, the brown-black soils of the plains and prairies, the gray-brown soils of the temperate-climate forest regions, and the yellow-red soils of the sub-tropical and tropical forest regions. A fifth group would include the alluvial soils of all the great river valleys of the Earth. And peat and sand might be thought of as two more groups.

The gray-red soils of the arid regious, which are called desertic soils, were formed under arid conditions of limited vegetation. Their chemical composition closely resembles that of the rocks from which they were made. Leaching losses have been restricted to those taking place during the occasional heavy downpours that have occurred. Desert soils have important agricultural value only as they can be brought under irrigation. Surrounding the desert are semi-arid lands that constitute highly important grazing areas for sheep and goats in many parts of the Earth.

When water is applied to desertic soils they are usually found to contain large amounts of soluble salts, including all the mineral elements needed by plants and man. As a rule, they are highly productive, and crops that are grown on them tend to be relatively high in ash elements and in protein. The primary problem in dealing with these soils, once irrigation water is supplied, is that of controlling the excessive salinity and alkalinity that often develops.

About one third of the land area of the Earth is desert, and large acreages immediately surrounding the deserts are not far removed from this condition. Irrigation would make them productive, but water is not to be had. It must be collected in distant mountains and made to flow to the points where it can be most profitably used. Of some 150 million acres of desert and nearly 600 million acres of surrounding arid land in the United States only 27 million acres is now being irrigated. Enough more water is in sight for possibly 20 million acres more.

The brown-black soils of the plains and prairies, commonly called chernozemic soils from a Russian word meaning "black earth," were formed under conditions of moderate rainfall and a natural grass cover. Their dark color is due to organic-matter accumulations resulting from lush spring growth of grass followed by drier summer conditions under which the rate of decomposition of grass residues was relatively slow. The rainfall, though not heavy, was sufficient to leach out and carry away the readily soluble salts, including the alkaline sodium and potassium carbonates that present such troublesome problems in desertic soils.

The less-soluble calcium carbonate remained behind to stabilize the humus and form a calcareous deposit. The location of this deposit depends on the amount of rainfall to which the soil has been

subjected. It may be on or near the top of the soil, a foot or more below the surface, or down deep in the subsoil. With increasing rainfall it finally disappears entirely.

Chernozemic soils cover wide expanses of land. These include the great wheat- and corn-growing areas in central United States, the large wheat belt in the Ukraine of the U.S.S.R., and a similarly large area in Argentina. These soils are highly productive of virtually any crop adapted to this climatic environment. Such crops include the acid-sensitive alfalfas and sweet clovers, which are noted for their high content of all the essential mineral elements, including the extra ones required by man. They are also noted for their high content of high-quality proteins.

During years of favorable weather high acre yields of first-class food crops are possible on these soils. And the fertility of such soils is long-lasting, with a crop-growing potential of many years without supplemental need of soil amendments. When such amendments are required, rates of application need not be so large as are necessary in the heavier-rainfall regions. The most troublesome limiting factor in crop production on these soils is the frequent lack of adequate rainfall to meet crop requirements. This applies particularly to the drier portions of these areas where wheat becomes the dominant grain and corn is or should be replaced by grain sorghums.

The gray-brown soils, commonly called podzolic soils from a Russian word meaning "ashes," predominate over the cooler and moister agricultural regions of the Earth. These soils were formed under conditions of relatively high rainfall and heavy forest vegetation. They have been subjected to considerably more leaching than the chernozemic soils. As a result they have lost not only their soluble salts but their calcium carbonate as well. Thus they are low in available mineral nutrients and they tend to be strongly acid. They are characterized by a grayish-white zone of badly-leached soil just above the subsoil.

Podzolic soils owe their special importance to the dependability of the rainfall in the regions where they exist and the long summer days that prevail. These make them particularly valuable for the production of spring grains, mixed hays, and pasture grasses. And they are also very useful for growing such cool-weather crops as potatoes, peas, and sweetcorn.

But these soils must be limed and liberally fertilized. Even so, it is difficult to grow the acid-sensitive and mineral-rich legumes that thrive naturally on the chernozemic soils. Special attention has to be paid to supplying plenty of potassium. And the several secondary and trace elements are often needed as well.

The yellow-red soils of the sub-tropical and tropical regions, commonly called latosolic soils from a Latin word meaning "brick," are the product of still heavier rainfall and higher temperatures than prevail in regions of podzolic soils. This has resulted in the loss of not only the soluble salts and calcium carbonate but a considerable part of the silica as well. The true Latosols of the Tropics consist largely of iron, aluminum, and titanium oxides. They are nutrient-poor soils.

Latosolic soils are not strongly acid and they do not require such heavy liming for crop production as podzolic soils. But many problems are involved in keeping such soils in place after the protective forest cover is removed. And large amounts of nitrogen and mineral nutrients must be applied annually to produce satisfactory yields.

In strong contrast with the good opinion of Crookes, who dealt with the Tropics in relation to food production of the future in his address before the British Association for the Advancement of Science in 1898 and expressed the opinion that they had highly important potentialities (7), Stamp labels them "regions of lasting difficulty" (16). And De la Rue says: "The legend of the inexhaustible fertility of the soil of the hot countries has taken a long time to kill" (11).

At this point it becomes desirable to consider the element of Time. Soils may be young, middle-aged, mature, or in old-age depending on the length of the period during which they have existed in their present location. And, on many occasions, catastrophic happenings have rejuvenated old soils over vast areas of the Earth.

Alluvial soils, which have often been built up to great depths from soil material that has been eroded off of lands farther up the stream, may be renewed annually, as in the Valley of the Nile. Such soils are usually fertile. But erosion of the uplands from which their soil materials are being derived may finally result in the land's being covered with much less productive subsoil.

The several southward invasions of glaciers from the Artic regions, terminating about 25,000 years ago, ground up underlying soil and rock and mixed them thoroughly. The soils of Canada and of the northern part of the United States, as far south as the Ohio River, were thus restored to a high state of fertility. The winds that blew across the retreating glaciers carried great quantities of silt to form deep deposits of fertile loess over a large part of central United States.

Similarly, large areas of land, notably in the tropical regions, have been covered with deep deposits of volcanic ash within relatively recent times. Some of the most productive soils on Earth have been formed from such ash, of which those of the sugarcane lands of Java and of the ricelands of southeastern Asia are good examples.

A number of highly important changes in the mineral and organic makeup of plants occurs as we move from the irrigated arid lands toward the Tropics. Bear and associates have shown that total ash, calcium, potassium, and trace-element contents of vegetables decreased eastward from the irrigated desertic soils of Colorado to the chernozemic soils of the Central States and still more to the podzolic soils farther east (6). Manganese was a marked exception to this rule. The content of this element in vegetables tended to increase materially toward the east, with the greater acidity of the podzolic soils. Their magnesium content tended to decrease from New York southward to Georgia.

The protein values of plants fall materially as we move eastward from the irrigated areas to the chernozemic and podzolic soils and southward to the Tropics. In general, tropical plants are relatively low in protein and high in carbohydrates. Albrecht and his associates point out that the quality of their proteins is also lowered, with ever-greater likelihood of deficiencies of some of the essential amino acids,

notably tryptophane and methionine (2,14). These changes in protein and amino-acid values are closely related to the lessening supply of soil-derived nitrogen and sulfur at the plant's disposal and to reduction in the amounts and to changes in the ratios of the several mineral nutrients.

An important principle in the mineral nutrition of plants merits consideration in this connection. This is that elements of similar properties can be substituted for each other, within reasonable limits, without materially reducing yield or affecting the appearance of the plant. Yet the sum of these elements in a given species and variety of plant is essentially a constant (3). This assumes uniformity of the climatic environment of the plants grown for comparative studies, a specific stage of growth at harvest, and expression of values as milliequivalents rather than percentages.

But a wide range of values of each of these elements will be found, depending on the relative amounts of them at the plant's disposal. Thus, of the calcium-magnesium-sodium-potassium group, if extra supplies of potassium are provided for the plant, the content of that element will increase, but the contents of the other three will diminish to a corresponding degree. It happens that potassium is the most mobile ion of this group and magnesium the least. As more and more potassium is supplied to the plant, serious magnesium deficiency tends to develop.

Sodium plays very little part in this constant in the field unless we are dealing with saline soils or with those that have been liberally fertilized with sodium-containing salts, such as nitrate of soda or sodium chloride. In humid regions virtually all the available sodium has long since been leached out of the soil and carried out to sea. Some crops, notably beets and celery, are capable of absorbing large amounts of sodium, and they produce materially larger yields when it is available for use.

If the plant absorbs its nitrogen in the ammonium form, this constitutes another competitor with the four base-forming mineral elements in arriving at an electrostatic balance within the plant. If the plant absorbs its nitrogen as the nitrate, competition with phosphate, sulfate, and chloride ions is involved. These four acid-forming radicals, in conjunction with silicates, constitute a second group of which the milliequivalent summation values in specific plants tend also to be a constant.

In this case nitrate is the most mobile ion. Increased uptake of nitrate tends to reduce that of phosphate and sulfate. And chloride enters the picture to a marked degree in saline soils and following applications of increasing amounts of potassium chloride as a fertilizer. Although plants require chlorine, a mere trace will suffice. In Europe it is common practice to apply potassium chloride in the fall with the hope that most of the chloride will have been carried off in drainage waters as calcium chloride by the following spring.

The position of the silicate ion in plant nutrition is not well defined. In many ways it is similar to that of sodium. Both elements are difficult to eliminate from solutions that are designed to test nutrient requirements of plants. But there is considerable evidence that silicate, like sodium, has a beneficial effect on some crop plants,

notably on rice. And there is good reason to believe that it has a partially substitutive value for phosphate in plants.

We are now ready to consider the mineral quality of crop plants in relation to the mineral needs of man. But we know more about this in animals than we do in man, so it seems best to consider them first. Livestock are more likely to feed on the produce of only the soil on which they live than is man, and any lack of a given mineral nutrient in that soil may soon show up in an identifiable symptom of deficiency.

The most widespread mineral deficiencies of livestock are those of sodium and chlorine, elements that are normally present in only relatively limited amounts in plants, except for those grown on saline and sodium-treated soils. We are so accustomed to using salt as a mineral amendment to feeds that we seldom think of its constituents in terms of mineral deficiencies in feed crops. But these two elements constitute true mineral deficiencies in feed and food.

The body of a 1,000-pound cow contains about 1 pound of sodium. During the course of a year the feed she eats, if grown on a soil of the humid regions, will contain about that amount of the element. But standard practice calls for feeding such a cow about 35 pounds of common salt during the year. Of this about 14 pounds is sodium. The remainder is chlorine. The amounts of chlorine in feed crops are not so definitely known.

The particular significance in the feeding of common salt to livestock lies not only in the fact that it represents a mineral deficiency in feed but that we are meeting this deficiency by supplying a purely mineral salt. Nobody ever suggests that we apply this salt to the field so it can first be built up into organic compounds inside the plant. Common salt, as such, appears to be essential to all herbivorous animals. Carnivores get what they need by devouring other animals.

Other well-known and widely-distributed mineral deficiencies in livestock include those of phosphorus, cobalt, and iodine (12). These deficiencies are so widespread and the symptoms at their worst stages are so clearly recognized that salts of these elements are being used as supplements to grain feeds not only in areas of known need but quite generally the country over. Here again we feed purely mineral salts directly to livestock to correct the deficiencies of these elements in forage crops. Phosphorus is the only element in this group that is known to be required by plants. A deficiency of this element can often best be remedied by applying phosphate fertilizers to the soil on which feed crops are being grown.

Increasing incidence of "grass tetany" in livestock in this country and abroad, notably in Holland, indicates deficiencies resulting from the uptake of an excess of one element at the expense of another. In this case we seem to be dealing with a deficiency of calcium and magnesium, particularly the latter, resulting from excessive absorption of potassium by forage crops. Some of the most troublesome cases of this in the United States have been found in livestock grazing on winter wheat in the relatively-low-rainfall areas to the west (8). Injections of calcium and magnesium gluconates constitute the best-known remedy in acute cases. Salts of these elements could probably

be added to common salt to advantage as a preventive measure in such areas. Where the soil is acid the recommended remedy is an application of a dolomitic form of liming material to it (17).

A considerable number of other elements are known to be present in excess in forage plants over large areas of grazing land. These include selenium in a wide belt extending from the Dakotas southward to Mexico City, molybdenum in certain parts of Florida and California, and fluorine in areas in close proximity to phosphate deposits and to industrial plants where hydrofluoric acid is released to the atmosphere. Here and there trouble is experienced from feeding forage that contains excessive amounts of nitrate (5).

In most if not all of these cases the difficulty may lie not so much in the excess of some element but in the deficiency of another element that was replaced by it. In other words, the problem is one of balance among the several elements having similar properties that are absorbed by plants and consumed by the livestock feeding on them. The antidotal effects of iron on manganese toxicity in plants and of copper on molybdenum toxicity in animals (9) are good examples. In remedial measures we may choose between supplying more of the deficient element or finding some means of getting rid of the one in excess.

An interesting example of what is probably a mineral-nutrient imbalance is found in hogs. It has long been known that it is dangerous to feed common salt to fattening hogs. But there is good reason to believe that no such difficulty would be experienced if these hogs had access to good forage. By grazing on such forage a suitable balance among the several similar mineral elements would probably be effected.

Suckling pigs on clean cement or board floors often develop anemia that can be remedied by painting the sow's teats with dilute solutions of iron and copper sulfates. Such difficulties are seldom experienced where the pigs have access to soil in which they can root and out of which the necessary minute quantities of these trace elements can be obtained.

The evidence indicates that poultry nutritionists have a somewhat clearer notion of what is required in meeting the mineral needs of their birds than do livestock nutritionists and those having to do with man. Completely synthetic diets have been developed for poultry in which the mineral nutrients are prescribed in quite definite amounts. It is of interest to note that the mineral mixture that is being used in such studies consists of specific quantities of some 12 salts that are made to constitute a little over 5 per cent of the ration.

Much less is known about mineral deficiency and imbalance in man than in livestock. In the Occidental countries it is generally assumed that this problem is safely disposed of by eating a considerable variety of grains, fruits, and vegetables from widely-distributed points of origin and by supplementing these foods with ample quantities of meat, eggs, and milk. The case for the Orient is not quite so clear, since the individuals of those countries have less food to eat, more of it comes from the localities in which they live, and animal products are not available on such a large scale.

But we begin with the natural deficiency of sodium and chlorine. In meeting this deficiency many people have gone to such extremes

that they find it necessary in due time to go on a "salt-free" diet. It seems probable, however, that this is largely if not entirely another case of imbalance in which excessive sodium unduly replaces the other elements of its group and excessive chloride replaces some of the essential acid-forming elements.

Of the other widely-known mineral deficiencies of man those of iodine in relation to goiter and fluorine in relation to tooth decay are the ones most commonly mentioned. We do have, however, a considerable variety of anemias of the type that require the use of iron, copper, and cobalt for remedial purposes. Many of these appear to be due to malfunctioning of certain body organs. But it is difficult to know which is cause and which is effect. There must be some fundamental cause or causes for such abnormalities, of which imbalance in the mineral diet might well be an important if not *the* most important one.

It appears probable that any troubles with mineral deficiencies that may be experienced by man in this country are not due to any lack of variety of foods from which good balance could be effected but poor choice in what is eaten. Children tend toward too high consumption of the high-carbohydrate and low-mineral foods and drinks, such as candies, cookies, ice creams, and soft drinks. Middle-aged people often substitute alcoholic drinks for more substantial foods. And those in old age tend to consume too much of the foods that are easy to come by, such as bread, rolls, coffee, and tea.

Williams has presented ample evidence that every man has a chemistry of his own (19). This applies to the size and shape of his organs, his digestive processes, his nutritional needs, and his excretory pattern. Much of the malfunctioning of the bodies and minds of men in physical and mental distress can be accounted for in some abnormality of their chemistry. Some highly effective chemical remedies, including vitamins and mineral mixtures, have apparently effected cures for what were formerly believed to be incurable maladies. Nevertheless there must be some norm around which all the elements of nutrition, including minerals, can be organized for the general welfare of the people as a whole.

Factors other than soil and its produce may operate to man's advantage. De Castro points out that although the calcium and phosphorus contents of tropical foods are relatively low and the people, as a result, tend to be small in stature, their bony structures are solidly built. He credits this to the production of extra amounts of vitamin D, a highly important aid to calcium utilization, by the sun's action on the bare skins of the people in these regions. And this, no doubt, affects better utilization of phosphorus as well (10).

The produce of an unthrifty plant may be better from the point of view of protein and mineral values, other than the one in most serious deficiency that limits yield, than that of a plant in luxuriant growth. In general, protein and ash values decrease with increasingly high acre yields, the larger part of the yield increases being carbohydrates. Considering the fact that our growing population will require higher acre yields and that less animal products per person will be available for consumption in due time, it seems likely that the problem of protein and mineral nutrition may become more troublesome.

The inorganic composition of soils affects the organic composition of plants growing on them. The best example of this is found in protein, the content of which in plants is mostly determined by the amount of available ammonium and nitrate nitrogen in the soil. Even legumes are not exceptions to this rule since they synthesize their protein through the use of the nitrogen gas, an inorganic form of nitrogen, of the atmosphere. Another example is methionine, an amino acid that is essential to both animals and man. This acid can be synthesized by plants only as adequate supplies of sulfate are present in the soil.

Ruminants have a very considerable advantage over man in that, with adequate supplies of carbohydrate at their disposal, the rumen microbial flora can make use of mineral nutrients to synthesize all the compounds they require. They can produce their own vitamin B_{12} from cobalt sulfate. They can even synthesize amino acids from urea. Recent studies with solutions of urea, phosphoric acid, ethyl alcohol, and molasses indicate that little if any of the protein forms of nitrogen need by supplied to beef cattle.

The case for man is a much more complicated one. Not much synthesis is to be expected from the microflora of the intestinal tract, although this is not entirely ruled out. But this means that nitrogen and at least two of the mineral nutrients—sulfur and cobalt—must largely be supplied in organic forms. This calls for a balanced diet of proteins that will supply the several essential amino acids, including the sulfur—containing methionine. And cobalt must be in the already-synthesized B_{12} form.

So far as is now known, all the mineral elements except sulfur and cobalt can be supplied to equally good effect in either inorganic or organic forms (13). That being the case, it would seem much easier to effect mineral balance in the food of man through use of a salt shaker containing a well-balanced mineral mixture than by way of applications of mineral amendments to the soil. And, except for the fact that the organic as well as the inorganic constituents in foods must be kept in balance, the salt-shaker method would appear simpler than that of selecting from among the many food products at man's disposal.

The nitrogen and mineral values in soils are adjusted to the needs of plants rather than to those of animals or man. The primary aim of the farmer is to increase acre yields and to develop quality only so far as it means extra feed value or eye appeal. Many food processors, however, stress particular food constituents, including calcium and phosphorus, methionine and other amino acids, and the several vitamins.

But much more attention is being given by biochemists to organic than to inorganic food values. And trace elements, as a group, are seldom dealt with in any detail, although they are probably equally as important as vitamins from the point of view of human nutrition.

The mineral composition of man, as to the major and secondary elements, is now fairly well-known (15). We are somewhat uncertain about the trace-element content of a normal man. And we still need to know what constitutes a balanced mineral diet for man. So far, about the only specific recommendation on mineral nutrients as such

is that the calcium-phosphorus ratio in the food should be of the order of 1:1½. But there is doubt even on this, Canadian biochemists preferring a 1:1 ratio (1).

Except for the occasional objector (18), potassium is dismissed with the statement that foods will normally contain adequate amounts of it. No specific suggestions are offered with respect to magnesium. Meanwhile we keep pouring on common salt at the table even though the food was well salted in the cannery or the kitchen. And then we eat salted peanuts, pretzels, and potato chips on the side. Our trace-element needs are presumably met by putting iodine in the salt and fluorine in the drinking water, and taking pills that contain vitamin B_{12}.

Balance among the several mineral nutrients is essential to plants for both well-being and yield. Some fairly definite soil values for available supplies of these elements have been established. For example, best results for most crops grown on podzolic soils can be expected if the hydrogen, calcium, magnesium, and potassium ratios in the soil's exchange complex are maintained at about 20:65:10:5, respectively, expressed as milliequivalent percentages. The pH value of such a soil would be around 6.5.

The plant's hydrogen is derived from water. But its needed supplies of the other three elements in this group are obtained primarily from the soil's exchange complex. The ratios of these elements in a good corn crop are of the order of 2:3:5, respectively, in contrast to the 13:2:1 ratios in which they exist in the exchange complex of the "ideal" soil, both sets of ratios being in terms of milliequivalents.

The relative rate of uptake of these elements by a plant depends on the relative intensities with which they are adsorbed on the soil's exchange complex. But it depends also on the rates at which these elements can pass through the cell membranes of the roots and of the plant's interior in response to electrostatic forces within the plant. Further, they depend on the rate and extent to which these elements are removed from solution by precipitation or by being bound in some nonionizable form in the plant cells.

But the law of mass action is in continuous operation. For example, all the elements in the soil's exchange complex can readily be replaced by ammonium in accordance with this law by extracting the soil with ammonium acetate.

The ratios in which these elements exist in a farmed soil's exchange complex depend on the relative amounts of them that are supplied in the form of liming materials and fertilizers. And any changes in these ratios in the soil's exchange complex will be reflected in the ratios in which these elements are absorbed by a plant growing on that soil. And they will also be reflected in any excretions of these elements, whether by way of the roots of the plant or from the leaves as they are being washed by rains.

This same principle of mass action applies to any intake of mineral elements from the alimentary tract of man. And it applies to their distribution and fixation within the body and to their release by way of the urine and feces. As with plants, selectivity will be effected by the several membranes and organs, but that does not interfere with the application of the principle.

For example, any abnormal intake of common salt by man is certain to result in a tendency toward potassium deficiency on the one hand and a phosphorus deficiency on the other, with a lesser tendency toward deficiencies of other mineral cations and anions. A larger percentage than normal of the displaced ions will be excreted in the urine and feces. And this same principle of mass action applies to all the needed trace elements in case of excess intake of any one of them.

If biochemists could develop a set of ratios of all the mineral nutrients that would be favorable to nutrition of man, the soil scientist could plan a soil-fertility program that would aid materially in developing these ratios in the food we eat. Failing this, farmers and fruit growers are quite likely to continue those practices that produce the highest acre yields consistent with economy of production, and without reference to mineral quality. They will, of course, try to improve those qualities that appeal to the eye and taste or that result in least deterioration in shipping.

It is surprising that man survives as well as he does, considering how he deals with himself in the selection of food and drink. Fortunately, the body of man has considerable capacity to hold on to the elements in deficiency and to excrete those supplied in excess. What are known as "homeostatic mechanisms" protect us against ourselves. But we are subject to a lot of ills along the way that might be warded off with intelligent assistance from those who are responsible for producing the foods we eat. These include those who have to do with maintaining a suitable mineral balance in the soils on which crops are to be grown.

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Some Facts On Fertilizer Consumption and Use In The United States

L. B. Nelson[1]

The purpose of this paper is to review briefly some of the more recent information on fertilizer consumption and use in the United States and territories. Changes are constantly occurring. And, because of the great influence fertilizers exert upon our national agricultural economy, it is of interest to follow these changes. The American farmer, for example, invests annually over one billion dollars in the purchase of fertilizers. It has been estimated also that fertilizers are responsible for 20 percent of the nation's farm output since 1940.

Fertilizer consumption in the United States almost tripled from 1940 to 1953. Consumption jumped from 8,656,000 tons in 1940 to a peak of 23,421,000 tons for the year ending June 30, 1953.[2] Tonnages then declined slightly with each succeeding year until a low of 22,193,000 tons was reached in 1955-56. However, it is estimated an increase of 292,000 tons occurred in 1956-57. Total consumption of primary nutrients (N, P_2O_5, and K_2O) has increased each year since 1940 except for 1955-56. For the year ending June 30, 1957, estimated primary nutrient consumption reached the all time peak of 2,125,000 tons of nitrogen, 2,243,000 tons of available P_2O_5, and 1,935,000 tons of K_2O. Greatest percentage increases in fertilizer use since 1940 have occurred in the west North Central, Mountain, and Pacific States and the least in the New England, Middle Atlantic, and South Atlantic States.

About two-thirds of all fertilizers are sold as mixed goods. This ratio has changed little in recent years. There has, however, been a consistent upward trend in the primary nutrient content of the mixtures. For example, the nutrient content in 1930 was 17.9 percent; 1940, 19.9 percent; 1950, 23.6 percent; and 1955-56, 28.3 percent.

Currently there are over 1,400 grades of mixed fertilizers being marketed in continental United States. Total tonnage of the fifteen principal grades in each region account for 60 percent of the total tonnage in 1955-56. There seems to be little progress toward fewer grades even though fertilizer specialists feel that a relatively small number of grades would meet the country's needs. In 1955-56, about 90 percent of the tonnage of all mixed fertilizers was N-P_2O_5-K_2O mixtures; 6 percent, P_2O_5-K_2O; 2 percent N-P_2O_5; and 1 percent N-K_2O mixtures. During 1955-56, 5-10-10 was consumed in largest tonnage, although in each of the six preceding years 3-12-12 was the predominant grade. From 1943 through 1949, 2-12-6 was the most popular.

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[2]Unless otherwise indicated, sources of information used for this presentation are the annual fertilizer consumption reports of Walter Scholl and his coworkers.

About 59 percent of the nitrogen, 21 percent of the P_2O_5, and 12 percent of the K_2O consumed in the United States is for direct application. Urea, anhydrous ammonia, and aqua ammonia are gaining in popularity while all other nitrogen materials used for direct application appear to be decreasing.

Granulation of mixed fertilizers has increased rapidly during the past six years. According to Hignett and Slack,[3] 3 to 4 million tons of mixed fertilizers are now granulated. This approximates a 3-fold increase in the past two years. About 75 percent of the mixed fertilizer consumed in Texas, Oklahoma, and Kansas is now granular. This popularity of granular materials appears to reflect the desire of farmers for fertilizers having better physical properties.

The estimated use of primary nutrients by crops in the United States during 1954 is given in Table 1. The data indicate that high cash return crops have a higher percentage of their acreage fertilized and receive more fertilizer per acre than low return crops such as wheat and hay and cropland pasture.

TABLE 1.

ESTIMATED USE OF PRIMARY NUTRIENTS ON MAJOR CROPS IN THE UNITED STATES DURING 1954*

	% of harvested acreage fertilized	Ave. rate per acre fertilized		
	%	N Lbs.	P_2O_5 Lbs.	K_2O Lbs.
Corn	60	27	28	25
Cotton	58	49	31	25
Tobacco	97	60	121	117
Sugar Crops	91	58	46	14
Potatoes	78	71	108	98
Fruits	58	78	33	40
Vegetables	63	59	84	66
Wheat	28	18	27	19
Hay and Cropland Pasture	10	14	40	29

*Source: Fertilizer used on crops and pasture in the United States—1954 estimates. U. S. Dept. Agr. Statistical Bul. No. 216. 55 pp. Aug. 1957.

The percentage distribution of plant nutrient use by major crops is given in Table 2. These data show that a higher percentage of the total tonnage of each of the primary nutrients is applied on corn than for any other crop. Tobacco, sugar crops, and potatoes, although fertilized heavily, have only a comparatively small acreage and thus account for only a small percentage of the total nutrients consumed.

The geographic pattern of the percentage of the harvested acreage fertilized for all crops and cropland pasture is shown in Figure 1.

[3]Hignett, T. P. and Slack, A. V. Plant Practice in Granulation. Agr. and Food Chem. 5: No. 11, 814-831, 1957.

Figure 1. The percentage of harvested crop and cropland pasture acreage fertilized during 1954. Map prepared by J. R. Adams, L. B. Nelson, and D. B. Ibach, ARS, USDA, based on data from the 1954 U. S. Census of Agriculture.

The highest percentages of the acreage fertilized occur in the Southeast, the Middle Atlantic and the East North Central States, and in the irrigated areas of the Southwest. The lowest percentages occur in the Great Plains and non-irrigated arid regions.

TABLE 2.

PERCENTAGE DISTRIBUTION OF PLANT NUTRIENT USE BY CROPS IN THE UNITED STATES DURING 1954.*

	Total acreage fertilized	Individual nutrients		
		N	P_2O_5	K_2O
	1,000 acres	%	%	%
Corn	46,873	35.3	30.2	33.5
Wheat	14,034	7.0	8.7	7.7
Oats and Barley	14,781	7.1	9.4	8.4
Cotton	10,948	15.1	7.6	7.6
Tobacco	1,515	2.5	4.2	5.0
Sugar Crops	1,063	1.7	1.1	0.4
Large seeded legumes	4,831	1.0	3.6	4.4
Fruits	2,422	5.3	1.8	2.7
Potatoes and Sweet Potatoes	1,144	2.3	2.8	3.2
Vegetables	3,642	6.0	6.9	6.8
Hay and Cropland Pasture	12,672	4.2	11.6	10.5
All Other (including non-farm)	———	12.5	12.1	9.8

*Source: See footnote, Table 1.

Genetic Hazards of Radiation As Interpreted From Animal Studies

William L. Russell*

(abstract)

Studies on the genetic effects of ionizing radiation on mice conducted over the past few years have made it necessary to reconsider various aspects of the estimation of the genetic hazards of radiation in man. Determinations were made of the X-radiation-induced point mutation rates at seven specific autosomal loci for spermatogonia of mice. The mean mutation rate obtained when the males were exposed to a dose of 600 roentgens was $(25.0 \pm 3.7) \times 10^{-5}$ per roentgen per locus. This rate is approximately 15 times higher than the *Drosophila* mutation rate obtained in similar experiments. Although it is unwise to generalize from such experiments, it would be risky to ignore the indication that calculations of human hazards based on *Drosophila* mutation rates may seriously underestimate the damage. Additional information from the mouse work indicate that, although postponement of procreation for a few weeks following exposure to radiation would reduce the total risk of transmission of mutational changes, by excluding those induced in post-spermatogonial stages, further postponement would not give additional reduction in risk. Furthermore, in all experiments, the litters sired by irradiated males showed a slightly lower mean litter size than those sired by control males. These data indicate that adequate protection against the genetic hazards of peaceful uses of atomic energy may require a limitation not only of the average dose of radiation received by the population as a whole, but also of the dose accumulated by individuals.

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SYMPOSIUM: SOIL REACTION AND LIME

Characteristics of Liming Materials

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The value of lime as a soil ammendment has been recognized since the beginning of recorded history and characteristics of liming materials available for use on the soil have changed little since about 1886, when basic slag was added to the list of materials having significant basic residual action in the soil. Nitrate of soda and calcium nitrate, two other materials having significant physiological basicity were first used in Europe about 1830 and 1902, respectively (4).

The important recent advances in liming have come as a result of better understanding of how to use the different materials, and what is the best method of preparation of them for a given set of conditions. Burned limes, hydrated limes, and raw limestones of various degrees of fineness and composition all have a place. Evaluation shifts, of course, with changes in initial cost and transportation charges. This must be kept in mind in selecting or evaluating limes for various uses. For example, pulverized limestone is used almost universally in Florida, because good sources of both calcitic and dolomitic limestones are readily available. In Costa Rica, the writer found that an acceptable grade of calcitic limestone was available for grinding, but native dolomite does not exist. Sulfate of magnesia has been used to supply a quite general deficiency of this element in the soil. But even here a mistake probably is being made because magnesium oxide with its much higher concentration of magnesium can be shipped in at a much cheaper rate per unit of MgO. The question of rate of availability of the sulfate versus the oxide still is unanswered.

This in turn brings in another factor in the selection of lime sources. It has been adequately demonstrated that as superfluous anions such as sulfate and chloride are used in fertilizer mixtures, leaching of bases markedly increases. Reduction of these anions to the minimum required as plant nutrients, or as indicated by economy of source materials, will result in an equivalent reduction of leaching loss of bases.

NEW LIMING MATERIALS

Only two new materials carrying liming value have been mentioned in recent literature. These are "brown mud" from the aluminum industry and "quenched calcium silicate slag." Brown mud is a siliceous waste product from the extraction of aluminum from bauxite. In tests by Whittaker et al (19) it was found to approach the efficiency of other liming materials for crop production. Dry mud contains 23 percent SiO_2, 47 percent CaO, 10 percent Fe_2O_3, 3.5 percent TiO_2, 5.5 percent Al_2O_3, and 3.6 percent Na_2O.

The quenched calcium silicate slag was examined for basicity by applying it to two Tennessee soils (11). As a result of a 10 year lysi-

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meter study it was found that the slag was efficient in raising the soil pH and that outgo of calcium from soil to which two tons of either slag or lime was added, equalled about one-half of the input. Four repetitive applications of two tons caused an increase of three to four times the calcium outgo, and in every instance the outgo from slag was greater than from the lime. This indicates either that the reactivity rate of the slag with soil acidity exceeded that of lime in the soil, or that its initial solubility was greater than that of the lime applied.

INDIRECT SOURCES OF ALKALINITY

Certain other materials such as nitrate of soda, calcium nitrate, and ammonium nitrate conditioned with lime are not new materials, but they are now being viewed in a different light than previously because of recent concern for subsoil acidity control. The ultimate residual effect of the basicity or acidity of these and other materials used primarily because of their nutrient value must receive full consideration in any modern program of fertilization. The various factors involved have been discussed at some length by the writer in a previous report (17). Briefly, the acidification or neutralization resulting from any given material is determined by the acidifying or alkalyzing potential of the ions left over after plant feeding. If ions such as sulfate, chloride, and nitrate are in excess they will unite with bases from the base exchange and leave hydrogen or acidity in place of the bases when leaching takes place. If the residue is of bases such as sodium, calcium, or magnesium it will replace hydrogen from the base exchange and reduce acidity. The theoretically ideal materials are those in which both ions are used, or in which bases are left as the residue.

Much has been said in the past about the high leaching potential of carbonic acid in the soil. This probably is true for soils above pH 6.0 where stable bicarbonates can form and persist, but there is considerable question as to the real significance of mobility of bicarbonates through a soil horizon below about pH 5.8. Tests by the writer in which calcium bicarbonate was added under one atmosphere of CO_2 pressure showed rapid reaction with soil acidity up to pH 5.8. Thus it is assumed that cations carried as bicarbonates will not readily pass a horizon below 5.8 but react with the soil until this pH value is approached.

The most active promoter of leaching under average practice probably is the sulfate ion which, because of its greater potential, will carry bisulfates through quite acid horizons. It appears that our thinking on the matter of leaching has been much confused by concepts developed for conditions involving only rain water and CO_2, while actually leaching potential under modern heavy fertilization practice is that induced by competition between strong anion and cation residues in the presence of the soil base and anion exchange mechanisms. The potential introduced by the nitrate ion applied as fertilizer nitrogen or resulting from decomposition of humus is especially important.

An important factor frequently overlooked in evaluation of effect of mobile ions on subsoil pH is that the same correlation factor between pH and percent base saturation cannot be used for both sodium and calcium (17). More recent work by the writer (18) on the addition of calcium and sodium hydroxide separately and together to a virgin Leon fine sand of pH 4.45 showed the following characteristics of soil pH. Addition of a certain amount of calcium produced a pH of 5.22, while addition of sodium of equal total basicity produced a pH of 6.04. Substitution of only ten percent of the calcium with sodium produced a pH of 5.32, substitution of 20 percent, a pH of 5.69; while using one-half calcium and one-half sodium gave a pH of 5.96. This indicates that relatively small portions of sodium in the bases in a soil will produce an erroneous concept of total acidity as usually interpreted from soil pH.

The presence of soluble salts in solution was found to largely remove this differential between the two cations, but at the same time it reduced the apparent pH in both instances to a marked degree. The addition of calcium sulfate solution (initially pH 6.2) lowered pH values as much as 1.1 units in hydrogen-calcium saturated soils and as much as 2.9 in hydrogen-sodium saturated soils, the greater reductions occurring as acidity increased. Potassium reacted similar to sodium in all of the tests.

The replacement of hydrogen in strongly acid Leon fine sand by neutral salts was found to be appreciable. Twenty percent of the calcium in a given amount of calcium sulfate solution passing through the soil replaced hydrogen. It left retained calcium equal to 800 pounds of calcium carbonate per acre. With continued leaching the calcium replaced hydrogen equivalent to 3,000 pounds of lime per acre, although the percentage of calcium removed from the solution decreased as soil acidity was reduced and base saturation increased. Sodium salts were only about 38 percent as efficient in replacing hydrogen as were calcium salts, and nitrate salts were about 75 percent as efficient as the sulfates. This efficiency of neutral salts in reducing acidity in strongly acid soils is largely overlooked by soils specialists, because of the misconception that a neutral salt has no active basicity. The real effect is further obscured by misinterpretation of the depression of pH that is observed if the excess soluble salts are not leached away.

FINENESS OF LIMESTONES AND RATES OF PENETRATION OF LIME

There appears to be little agreement on the relative value of fineness of limestones. Hoyert and Axley (9) found that there was little difference in effect due to fineness with heavy applications of limestone, but that with light applications the difference in pH correction in favor of finer materials was significant. The greatest changes took place during the first two to four years, but in general, quantity was more important than fineness. Beacher et al (1) found that calcitic and dolomitic hydrates were equally effective in raising pH and in lowering replaceable hydrogen, aluminum and manganese, and in promoting clover growth. Limestones finer than 100 mesh were about

equal, but coarse dolomite was less effective for a given particle size than was calcitic limestone.

Meyer and Volk (12), working in Ohio, showed that lime coarser than 20 mesh had little effect on soil acidity. Twenty to 60 mesh induced little initial change, but after eighteen months approached the effect of the finer particles. One hundred mesh or finer reacted to maximum within eighteen months. Calcitic limestone was slightly more effective than dolomitic after six to nine months. They concluded that four to eight mesh is valueless, 20 to 30 mesh of value over extended periods, but that material should be finer than 40 mesh to be effective within one year.

The writer believes that much of the real significance of lime tests has been missed by inadequate statement of qualifying conditions. Reactivity of lime depends on five factors: 1—the initial pH of the soil; 2—the degree of stirring or disturbance of the soil during the reaction-period; 3—the fineness of the material; 4—the relative reactivity of the material, as determined by composition and purity; and 5—the presence of strong anions such as nitrate, sulfate, and chloride necessary to distribute and equalize acidity for distances away from the nucleus of activity in the vicinity of the lime particle.

Longnecker and Merkle (10) recognized the immobility of lime and the limited extent of effect on surrounding particles, but did not introduce the strong anion equilibration factor.

It appears that the degree of fineness of limestone that is acceptable depends first on the initial acidity of the soil. If it is high such as maintained for Irish potato culture, then coarse lime will be sufficiently reactive, and even possibly desirable for a more controlled reaction. Coarse lime will give nuclei of effectiveness of high pH on solubility of other ions such as molybdenum, where contact root feeding can obtain necessary elements without subjecting the entire feeding area to this condition. It may be that the heterogeneous condition of acidity is an actual benefit to plants providing areas of both high and low pH for selective feeding or combination with disease control. Another factor omitted from most tests is simulation of cultivation. Undisturbed soil such as exists in meadows will react entirely different than frequently stirred soil.

Soil chemists have no effective means of determining the true micro differences in pH in associated areas of the soil. When a soil is collected, mixed, and pH determined, obviously a homogeneous condition has been developed from an essentially heterogeneous one. For this reason a knowledge of the liming practice during the past year or two usually is more valuable than the pH determination itself. An excellent example of this came to attention where lime had been applied to citrus. Repeated pH determinations by a private concern showed acidity greater than recommended for citrus. Lime was applied several times without significant effect. The writer sampled the area by profile and found a shallow surface pH much above the recommended value for citrus and subsurface pH still approximating that of the unlimed acid soil. No damage was done to the citrus by this condition, because the excess lime was unreactive on the surface, but tillage, if and when it did take place, could have produced a serious overliming condition on this particular low zinc soil. The importance

of micro-profile sampling of areas where lime has been used and tillage not practiced cannot be over-emphasized. Much of the information published to show the significant rate of penetration of lime into the profile ignores the effect of neutral salts produced or applied at the surface (2, 5, 8, 14). As stated before, observed pH changes in the range below about 5.8 probably are due to the effect of salts other than basic lime (calcium bicarbonate).

Numerous methods have been proposed for the determination of rate of reactivity of limestones of various types and fineness. Recently, methods have been proposed by Thomas and Gross (16) and Gibaly and Axley (7). These types of methods probably do have certain value, but also have a common weakness in that the estimate is based on a complete separation of the lime particles for reaction tests rather than maintaining the lime in its semi-aggregated state as exists in field usage, and which differs with limestone of different degrees of fineness.

EFFECT OF LIME SOURCES ON CROPS

In general, it appears that calcium uptake by plants is predominantly from calcium that exists as soluble or exchangeable sources rather than by contact feeding on calcium carbonate particles. However, Ririe and Toth (13), using Ca45, found that calcium from $CaCO_3$ was more available than that from $Ca(H_2PO_4)_2 \cdot 2H_2O$ or gypsum. This is further emphasized by the work of Schmehl et al (15) who showed that alfalfa obtained about 80 percent of its calcium from a layer limed with tagged calcium carbonate. The rate of reaction of $CaCO_3$ with the base exchange or other hydrogen probably is a confusing factor in the interpretation of all such data.

The placement of lime is very important, but apparently the best method must be determined specifically for each soil and crop combination. The tendency is for a crop to obtain its lime from the surface soil by preference (15), but liming of the subsoil will increase root development and calcium uptake by roots so located.

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The Relationship of Soil Reaction to the Activities of Soil Microorganisms—A Review

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Pasteur (21) was one of the first persons to observe that microorganisms can develop only in media having a specific pH range. A "feeble acidity," he said, "hinders the development of bacteria and infusoria and favors, on the contrary, the growth of molds. Neutrality or slight alkalinity acts in a precisely contrary manner."

Since the time of Pasteur many scientists have studied the effect of pH on microorganisms. For example, Winslow and Falk (34) have shown the percentage survival of *Escherichia coli* at various reactions, table 1. A reaction of about pH 6.0 was the most favorable for the viability of *E. coli* in distilled water. All microorganisms exhibit variations in survival or in metabolic processes with changes in pH.

TABLE 1.—VIABILITY OF *Escherichia coli* AFTER 9 HOURS IN DISTILLED WATER AT 37° C. (FROM WINSLOW AND FALK 1923)

	pH					
	4.0	5.0	6.0	7.0	7.5	8.0
Percentage of bacteria surviving	1	82	106*	54	35	12

*A slight increase in cells occured at this pH value.

Although strong solutions of mineral acids are quite destructive to most forms of life, certain microorganisms possess a remarkable tolerance to them. For example, according to Porter (22), the sulfur-oxidizing bacterium *Thiobacillus thiooxidans* will grow at reactions of pH 1.0 or below, and the nitrogen-fixing bacterium *Azotobacter indicum* will grow and fix nitrogen in media with a pH as low as 3.0. Probably the most acid-tolerant microorganisms known, however, are two fungi (*Acontium velatum* and a dark-green organism belonging to the *Dematiaceae*) which have been studied by Starkey and Waksman (25). Both of these fungi grow in synthetic media of pH 0.1 to 1.0. In contrast to the acid tolerant organisms, Porter (22) stated that certain of the bacteria, such as *Rhizobium leguminosarum*, may survive at pH 11.0. A study of the literature, however, reveals that the vast majority of microorganisms grow and reproduce best in a pH range of from 5.5 to 8.0.

Why this variation in pH tolerance among microorganisms occurs is not entirely known. McCalla (19) is of the opinion that hydrogen ion is toxic or impairs the growth of the bacterial cell not because of any lethal effect but by holding the adsorption positions and preventing the combination of nutritive ions with the cell.

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The effect of acids on microorganisms cannot be related to the hydrogen ion alone. For example, the effect of the acid molecule is very important; this is shown by the comparative bactericidal dilutions of organic acids for *Pseudomonas aeruginosa* in table 2. Reid (23) found that in a given series of monobasic acids the bactericidal action increased with molecular weight and that the introduction of hydroxyl groups into these acids was found to render them two to twelve times more effective. He also observed that with organic acids the undissociated molecule plays a major role. For dibasic acids, however, the acidity was found to be proportional to the dissociation, and the bactericidal activity decreased as the series ascended. Of the two tribasic acids tested, aconitic was three to thirty-six times more toxic than citric for bacteria. Since organic acids alter the surface tension of solutions, Reid believed that this may be a factor in determining their toxicity.

TABLE 2.—Comparative Bacteriological Dilutions of Organic Acids for *Pseudomonas aeruginosa*, with pH Values.
(From Reid 1932)

Acids	Bacterial Dilutions	
	Normality	pH
Monobasic		
Acetic	0.33	2.7
Propionic	0.25	2.8
Butyric	0.12	2.9
Valeric	0.05	3.1
Hydroxy Monobasic		
Glycolic	0.02	2.7
Lactic	0.03	2.7
Dibasic		
Oxalic	0.003	2.9
Malonic	0.008	2.8
Succinic	0.200	2.7
Tribasic		
Aconitic	0.016	2.4
Citric	0.055	2.5

Cowles (9) studied the germicidal action of the lower fatty acids (acetic, propionic, butyric, valeric, caproic, and caprylic) against *Staphylococcus aureus* and *Escherichia coli*. He concluded that the germicidal action of the unbuffered fatty acids for the colon bacillus was due almost entirely to the nonionized fractions of the acids, whereas for the stapyhlococcus the action of the lower acids was due to a summation of the hydrogen ion and the undissociated molecules, but in the higher numbers of the series the germicidal action was due to the nonionized acid.

The disinfectant action of highly dissociated mineral acids, such as hydrochloric and sulfuric, depends upon the number of free hydrogen ions present per unit volume and not upon their normal strength according to Porter (22). However, the weak organic acids, such as acetic and benzoic, tend to exert a more toxic effect than would be in-

dicated by their degree of dissociation. Here the effect appears to be due, in most cases, to the whole molecule and is specific for each acid. For example, acetic acid has only 10 to 20 percent the toxicity of benzoic. These points are clearly shown in the data in table 3 taken from the experiments of Winslow and Lockridge (35). Winslow and Lockridge have also shown that water containing 12.80 ppm. of dissociated hydrogen sterilized a culture of *Escherichia coli* in 40 minutes, whereas only 4.85 ppm. of dissociated hydrogen was necessary to produce the same effect in a suspension of *Eberthella typhosa*.

TABLE 3.—Percentage Reduction *E. coli* in 40 Minutes by Mineral and Organic Acids in Tap Water.
(From Winslow and Lockridge 1906)

	100 Percent Reduction			
	HCL	H_2SO_4	CH_3COOH	C_6H_5COOH
Normality	0.0123	0.0166	0.0935	0.0199
Percent Dissociation	96.4	76	1.35	5.4
Parts per million Dissociated Hydrogen	12.80	12.60	1.26	1.07

Clark (8) found the hydroxyl group to be more toxic to all species of molds than the hydrogen ion and that molds differ specifically in their tolerance. Furthermore, to inhibit the germination of these molds, a concentration of the mineral acids 200 to 400 times that fatal to higher plants is required. According to Wolf and Wolf (35) most fungi germinate and develop best in acid media.

Waksman (31) has stated that there is no one particular reaction which is favorable alike to all groups of soil microorganisms. When the soil is acid, especially at a reaction less than pH 6.0, it may become injurious to the growth of many bacteria, notably the nitrogen-fixing types, and favorable to the development of fungi. This may be due to the repressed competition of bacteria for the available nutrients in the soil by increased acidity. On the other hand, a less acid or slightly alkaline soil reaction may be unfavorable for the development of fungi and beneficial for many of the soil bacteria. Thus, he stated, when the conditions are made unfavorable for the development of one group of organisms in the soil, another group may be favored.

The Nitrifying Organisms—The response of the nitrifiers to lime in acid soils is one of the most striking changes produced by this material. It is impossible, because of soil variation, to predict the exact pH at which a soil will produce the most nitrate. However, according to Waksman (30), nitrate accumulation will proceed until the soil has reached a pH of about 4.0. The amount of nitrate formed depends upon the initial reaction of the soil and its buffer and base content; the higher the buffer and base content of the soil, the larger will be the amount of nitrate formed for a certain change of reaction. Based upon optimum pH values for respiration and growth found in Waksman's text (30), it appears that the optimum reaction for the

nitrification process must be between pH 7.0 and 9.0. Data by Eno and Blue (11) also support the view that a pH range of 7.0 to 9.0 is optimum for nitrate production. This work also showed that the increase in pH need not necessarily be produced by lime for, in this case, anhydrous ammonia was added in sufficient amount to increase the pH above neutrality.

Nitrate may be found in very acid soils. This was explained by Hall, et al. (15) as due to nitrate formation occurring in moisture films surrounding the small isolated particles of calcium carbonate under acid conditions. The addition of calcium carbonate has, therefore, a decided stimulating effect on nitrate formation, particularly in acid soils. It is believed that lime does not stimulate the activities of the nitrifying bacteria so much as it serves as a base for neutralizing the acid formed from the oxidation of the ammonium salt (30). Arnd (4) stated that nitrate formation takes place readily in peat and muck soils if the reaction is not too acid and if the soil is properly inoculated with the organisms. Acid peat soils do not generally offer a favorable medium for the development of the nitrate forming bacteria. When lime is added, these organisms become very active, often leading to a rapid diminution of available nitrogen, as shown in table 4.

TABLE 4.—Influence of Application of Lime Upon Nitrogen Content and Nitrification of a Muck Soil.
(From Willis 1923)

Application of lime	Nitrogen Content of Soil	Nitrate Formation		Reaction	
		Original Soil	Incubated Soil	Original Soil	Incubated Soil
	%	ppm.	ppm.	pH	pH
None	1.120	28	114	3.67	3.56
1 Ton	1.203	38	142	4.15	3.80
2 Tons	1.151	37	162	4.37	4.24
3 Tons	1.108	35	178	5.02	4.80
4 Tons	1.054	37	205	5.46	5.24

In alkaline soils which are deficient in humus, calcium carbonate may have the opposite effect since it tends to liberate free ammonia from ammonium salts which, due to its toxicity, retards nitrification. This retarding effect was shown by data on nitrification in Arrendondo fine sand obtained by Eno and Blue (11) and is presented in table 5. The anhydrous ammonia addition increased the pH above neutral and resulted in free ammonia which retarded nitrate production especially during the first fourteen days. This is a rather unusual response of nitrification to lime and is seldom observed in practice. The more common response to lime is an increased rate of nitrification as shown by the data obtained by Eno (10), table 6, and Neller (20), table 7. Neller's work clearly shows the effect of lime on nitrate accumulation even in soils to which no additional ammoniacal nitrogen had been supplied.

TABLE 5—Nitrification of Anhydrous Ammonia and Ammonium Sulfate in an Alkaline Sand.
(From Eno and Blue 1954)

Treatment		Nitrate Nitrogen Lbs./A		Soil pH*		
Material	Nitrogen Lbs./A	14 days	28 days	After N Added	14 days	28 days
Anhydrous Ammonia	311	190	273	8.4	6.9	7.0
Ammonium Sulfate	311	272	287	7.1	6.8	7.0

*Initial Soil pH = 7.3

TABLE 6.—The Effect of Lime on Nitrification in Several Sandy Soils.
(From Eno 1953)

Lime Tons/ Acre	Lakeland fine sand		Leon fine sand		Orlando fine sand		Blanton fine sand	
	NO_3-N Lbs./A	Final pH	NO_3-N Lbs./A	Final pH	NO_3-N Lbs./A	Final pH	NO_3-N Lbs./A	Final pH
1	56	4.8	0	4.5	3	4.7	7	4.3
2	167	6.1	10	5.3	29	5.7	75	4.9
3	343	7.4	103	7.0	350	6.1	462	5.6
Initial pH		5.6		5.3		5.5		4.8

TABLE 7.—The Production of Carbon Dioxide from Soil of Limed and Unlimed Plots as Related to Other Biochemical Factors.
(From Neller 1920)

Plot	CO_2 Production in 8 Days	NH_3-Nitrogen Accumulation in 6 Days	NO_3-Nitrogen Accumulation in 28 Days	Nitrogen Fixation in 20 Days	Bacterial Numbers	Lime Treatment
	mgm.	mgm.	mgm.	mgm.	millions	tons/acre
11A	220.7	11.93	10.4	−0.02	2.5	None
11B	319.3	11.43	21.3	+1.35	6.2	2
21	198.7	11.37	16.1	−0.90	5.1	None
24	333.1	11.69	33.9	+7.00	6.5	2

Organic Matter Decomposition—Soil reaction is of considerable importance in the decomposition of plant and animal residues in the soil. Without the efficient transformation of these materials into their constituents, the soil would lack many of its valuable functions. Organic matter and its continual transformation provides for nutrient

element release, exchange surface, buffering capacity, improved structure, and energy and mineral material for the moderators of the soil—the microbes.

Decomposition of organic matter goes on in all soils, but the addition of calcium carbonate to an acid soil greatly stimulates the multiplication of bacteria, accompanied by an increase in rate of decomposition of organic matter as shown in table 8. Additions of excess calcium carbonate and especially magnesium carbonate, however, may become injurious to many of the soil bacteria (31).

TABLE 8.—Influence of Calcium Carbonate on Evolution of Carbon Dioxide from Soil
(From Konig)

$CaCO_3$ Added Percent	CO_2 Evolved Per Day Milligrams
0	181.3
0.04	223.6
0.10	308.4
0.20	416.4
0.40	455.4

Neller (20), table 7, has also shown the same effect of calcium on organic matter decomposition. The maintenance of actively decomposing organic matter in soil is of great importance and this process is most effective when the soil is properly limed and maintained in a desirable pH range.

Total Numbers of Soil Microorganisms—It generally has been considered that liming the soil, and therefore increasing the pH, results in an increase in bacteria and actinomycetes and a decrease in fungi. Data supporting this statement are found in table 9. Data by Neller, table 7, also show that an addition of 2 tons of lime per acre increased the bacterial population.

TABLE 9.—Influence of Soil Treatment on Numbers of Microorganisms in the Soil.
(From Waksman 1952)
(Numbers in Thousands per Gram)

Treatment of Soil	Soil Reaction pH	Bacteria	Actinomycetes	Fungi
Unfertilized	4.6	3,000	1,150	60
Lime alone	6.4	5,210	2,410	22

Waksman (30) has observed that alkalies and alkali substances generally favor the development of actinomycetes, while acid and acid substances retard their activities. The limiting acid reaction for the majority of soil actinomycetes is pH 4.8 to 5.0, although some species

may grow at as high an acidity as pH 3.0 to 4.0. The optimum is pH 7.0 to 8.5. On the alkaline side, the majority of organisms will still grow at pH 8.6 to 9.0, while some will grow even at more alkaline reactions.

The optimum reaction for the activities of protozoa, according to Waksman (30), was at first believed to be at the neutral point. Good growth was obtained in acid media. The limiting acid and alkaline reaction values for the growth of *Paramoecium caudatum* were found to be at pH 5.0 and 9.0; in other experiments paramoecium was reported to develop normally at pH 6.4 to 8.0; beyond these limits, development was restricted and encystment probably took place. Various soil ciliates, flagellates and amoebae were found to live and reproduce in artificial media at pH 3.5 to 3.9 on the one hand and 9.8 on the other. Testaceous rhizopods are most numerous in acid peat soils and are very scarce in alkaline soils.

In regard to algae, acid soils were reported by Waksman (30) to contain a different algal flora from that commonly found in alkaline or neutral soils. Apparently the effect of changes in soil reaction on the algal population has not been studied extensively enough to determine the species which survive at various pH values.

There is some indication that nematodes may survive in larger numbers at a pH of about 5.0 than near pH 6.0. This is shown by the data of Gammon and Kincaid (13) in table 10. The soil samples were taken from unfumigated shade tobacco areas and the data are admittedly of a preliminary nature but tend to confirm an inverse response of nematodes to increasing soil pH. Little is known regarding the reaction range for other groups of organisms commonly found in the soil.

TABLE 10.—Average Number of Parasitic Nematodes (Primarily Rotylenchus Sp.) per 150 ml. Moist Soil From Shade Tobacco Soil pH Plots. Examined by W. H. Thames.
(From Gammon and Kincaid 1957)

Soil pH (Ave. 4 Plots)	Parasitic Nematodes (Ave. of 8 Samples)
5.06	13
5.53	11
5.78	9
5.97	6
6.26	5

Effect on Non-Symbiotic Nitrogen Fixation—Lime exerts such a favorable influence upon the activities of *Azotobacter* in the soil that Christensen (7) suggested using the presence of this organism as an index of the lime requirement of the soil.

The amount of calcium carbonate which should be added to the soil, to obtain maximum nitrogen fixation, varies with the soil (30). This is due to differences in the buffer content of soils, in addition to differences in the initial reaction. A reaction equivalent to about pH 6.0 is found to be, in most cases, the limiting acid reaction for *Azoto-*

bacter. The optimum reaction for nitrogen fixation by *Azotobacter* in pure culture seems to be closely associated with the optimum reaction for growth. The optimum reaction for the development of *Azotobacter* is pH 7.0 to 7.8, while the limiting alkaline reaction was reported to be pH 8.8. Different species of *Azotobacter* may vary, however, in their behavior to the optimum reaction.

Comparison of the pH-growth activity curves of *Azotobacter* by Burk, Lineweaver and Horner (6) showed that in both free and fixed nitrogen the pH optimum occurred at about 7.8. The zero limit of activity for growth in N_2 was reached at pH 6.0, but uptake of combined forms decreased much more slowly to pH 4.5 or less. The limiting value for fixation was independent of environmental factors, including pN_2 and concentration of calcium. Starkey (24), however, isolated a species, *Azotobacter indicum*, which fixed nitrogen at a pH as low as 2.9, and reached a maximum at pH 4.0.

The fixation of nitrogen in soils of a greater acidity than the limiting reaction for *Azotobacter*, according to Waksman (30), is due to the activities of *Cl. pastorianum*, which has its optimum at pH 6.9 to 7.3, but can still grow at an acidity greater than pH 5.7. Growth of this organism can be obtained at pH 5.0. The nitrogen fixed under these conditions is much less than that fixed in soils supporting an *Azotobacter* flora.

Neller (20) has shown an increase in non-symbiotic nitrogen fixation when two tons of lime per acre were applied, table 7. Calcium carbonate stimulates nitrogen fixation and is not toxic to *Azotobacter chroococcum* at a concentration of 2% in mannite solution according to Waksman (30). Magnesium carbonate, however, is very toxic above 0.1 to 0.2 percent. Calcium exerts a protective influence against the injurious effect of magnesium.

The Influence of Reaction on the Growth of Symbiotic Nitrogen Fixation and Nodule Formation—The beneficial effects of liming on the growth of legumes have been recognized for centuries, Wilson (33). In one of the first agricultural chemistry textbooks published, Johnston (17) observed that the addition of "alkaline manure" often caused white clover to spring up spontaneously where it had previously refused to grow. Johnston also recognized that liming may so encourage the growth of legumes and other plants, with a resultant heavy feeding on the soil, that it could be said that "lime enriches the father and impoverishes the son." He quoted with evident approval the adage,

> Lime and lime without manure
> Will make both land and farmer poorer.

Since the beginning of agricultural experimentation the effect of adding organic and inorganic supplements to the soil, with and without limestone, has been a standard line of investigation. Fred, et al. (12) concluded from their review of papers on this subject that liming of most soils stimulates nodulation and nitrogen fixation by leguminous plants, but that it is possible to overlime soils having pH values close to pH 7.0

Symbiotic nitrogen-fixing bacteria have limiting reactions which are not so sharply defined, however, as in the case of *Azotobacter* and

Clostridium, Waksman (30). Of the nodule bacteria, the alfalfa organism is most sensitive to acidity and the lupine organism the most resistant. It was suggested that a correlation exists between the acid resistance of bacteria and acid resistance of higher plants. The critical reaction values of nodule formation are pH 4.0 and 9.0 to 10.0, with an optimum at about pH 7.0; this optimum may be higher or lower depending on the legume. Different biological types of alfalfa and soybean organisms may vary in their limiting reactions. In the case of the soybean organism one strain was found to have its acid limit at pH 4.0 to 4.5 and the other at 4.5 to 5.0. The optimum was found to be at pH 4.8 to 6.5 depending also on the strains; the alkali limit was not so sharp. With increasing hydrogen-ion concentrations (decrease of pH), nodule formation is decreased. According to Bryan, (5) alfalfa organisms do not survive a greater acidity than pH 5.0, red clover organisms pH 4.5 to 4.7 and soybean organisms pH 3.5 to 3.9. The optimum growth for all strains of alfalfa organism was found to be at pH 7.0, with a limiting acid reaction at pH 5.5. Lime, in addition to maintaining a proper soil reaction, is also needed as a source of calcium. Jensen (16) stated that nitrogen fixation by *Azotobacter, Nostoc,* and the symbiotic system requires a high concentration of the calcium ion, but not nitrogen fixation by *Clostridium.*

The fixation of nitrogen by legumes at different pH values varies with the species, but in general a reaction near neutrality is optimum with little nodulation or fixation at a pH below 5 and above 8. These limiting values refer to the pH of the soil solution (33). The following data of Virtanen (28, 29) provide practically the only extensive comparison of the effect of pH on assimilation of free and combined nitrogen. The values given are mg. per 10 plants. The absence of data indicates that the crop was too small for analysis.

Peas	pH				
	4.0	4.5	5.0	5.5	6.0
Inoculated	----	82	293	509	1180
NH_4NO_3	169	224	367	991	1245
Red Clover					
Inoculated	----	----	250	577	1075
NH_4NO_3	131	206	270	414	548
Alsike Clover					
Inoculated	----	----	291	672	1097
NH_4NO_3	180	432	641	964	1124
White Clover					
Inoculated	----	----	292	628	815
NH_4NO_3	182	412	822	1324	1743

The chief point of interest revealed by these data is that, although uptake of both free and combined nitrogen decreases with increase in acidity, the limiting pH values for the two processes are quite distinct. A pH of 5.0 or lower inhibited both the fixation of molecular nitrogen and nodulation, but not assimilation of ammonium nitrate.

Since calcium is usually applied to the field as limestone, most investigators ascribe its beneficial effect entirely to its neutralizing action, overlooking the fact that the calcium ion is of great importance

in the nutrition of many plants. Albrecht and his collaborators have emphasized this latter effect of calcium by means of a series of experiments in which the mineral elements were supplied by soybean plants as a base exchange complex rather than as inorganic salts. From this and similar work Albrecht (2, 3) concluded that lack of nodulation and nitrogen fixation by legumes on acid soils is due to both a high concentration of hydrogen ions and to a low level of calcium, and that addition of the latter as a neutral salt ($CaSO_4$) is two and one-half times as efficient in promoting the growth of the plants as is a decrease of the hydrogen-ion concentration. Although at no level of calcium could nodules be obtained below a pH of 5.5, at higher values calcium was much more effective than a decrease in acidity in stimulating their formation. Wilson (33) said the effect of calcium at a given level apparently depended on the extent to which the clay was saturated with the calcium ion and except for pH effects was independent of whether the supplementary ion, to complete the saturation, was hydrogen or base.

Graham (14) stated that magnesium plays a definite role both in the production of nodules and in fixation of nitrogen by the soybean, in that it renders the supply of calcium more effective.

Wilson (33) has said that the information presently available does not particularly support the view that calcium is specifically concerned with the symbiotic nitrogen fixation process, as has been claimed for fixation by *Azotobacter*. Rather calcium appears to have an effect on the general growth of the host plant in addition to its specific effect on the development of the bacteria. He further stated that the calcium ion may play a dual role in inoculated plants—one related to the general growth of the plant and the other to the specific function of nitrogen fixation.

Lime may also be harmful to the growth of leguminous crops. Scholz (26, 27) believed that the lack of iron frequently causes chlorosis in lupines, and that under certain conditions liming becomes detrimental because it precipitates available iron in the nutrient solution and thus inhibits nitrogen fixation and nodulation.

Transformations of inorganic compounds in the soil—Despite the fact that the most effort has been expended on reducing acidity in the soil, there are also some important functions of acids in making the soil more fertile. Many nutrient elements, such as iron, magnesium, sulfur, calcium, phosphorus, potassium and manganese are converted into soluble form by both inorganic and organic acids. The organic acids are formed from the decomposition of organic matter while the inorganic are formed from the activities of such microbes as the nitrifying organisms and the sulfur oxidizing bacteria. Most all of the organic acids are present in small quantities and transient in nature in aerable soils. Under anaerobic conditions the organic acids are usually more abundant. Carbonic acid is probably the most abundant organic acid in the soil and it reacts with many insoluble mineral forms converting them into more soluble forms. Probably the most important acids involved in mineral transformations in the soil are nitric, sulfuric, phosphoric and carbonic acids.

The insoluble phosphates added to the soil are subject to the activities of microorganisms largely in an indirect manner. The various organic and inorganic acids produced by the microorganisms interact with the insoluble phosphates, giving rise to soluble compounds (31). This is illustrated by the following reactions:

$$Ca_3(PO_4)_2 + 2\ HNO_3 \longrightarrow 2\ CaH\ PO_4 + Ca\ (NO_3)_2$$
$$Ca_3(PO_4)_2 + 4\ HNO_3 \longrightarrow Ca(H_2PO_4)_2 + 2\ Ca\ (NO_3)_2$$
$$Ca_3(PO_4)_2 + H_2SO_4 \longrightarrow 2\ CaHPO_4 + Ca\ SO_4$$

Orthoclase feldspar interacts with certain microbial products to give soluble potassium salts (31):

$$Al_2O_3 \cdot K_2O \cdot 6\ SiO_2 + 4H_2SO_4 \rightarrow Al_2(SO_4)_3 + K_2SO_4 + 6\ SiO_2 + 4H_2O$$
$$Al_2O_3 \cdot K_2O \cdot 6\ SiO_2 + Ca(HCO_3)_2 \rightarrow Al_2O_3 \cdot CaO \cdot 6\ SiO_2 + 2KHCO_3$$

Since it is an accepted fact that the soil is not homogeneous in regard to pH, it is quite possible that areas of extremely acid reaction exist in soils which have a measured pH of from 5.5 to 7.0. It is in these areas that the microbes, producing organic or inorganic acids, are most effective in bringing elements into solution from such applied materials as rock phosphate and certain of the native soil minerals.

The effect of reaction on the activities of plant pathogenic organisms in the soil. Waksman (30) discusses the fact that some plant pathogenic organisms are readily affected by certain hydrogen-ion concentrations of the soil which are not injurious to the growth of the host plant, as in the case of potato scab and wheat scab. Some organisms have a certain acid minimum or alkali maximum which permit methods of control. *Actinomyces scabies* and most other actinomycetes, for example, do not thrive well at pH less than 4.8; *Plasm. brassicae* is inhibited by an alkali reaction obtained by the addition of lime. *Bact. solanacearum* causes serious infection in acid soils, but seldom in neutral or alkaline soils. *F. lycopersici* causes minimum infection at pH 6.4 to 7.0; it has both an acid and an alkaline maximum. Changes in pH to effect control of these organisms are usually brought about by the addition of either lime or sulfur, depending on whether an increase or decrease of acidity is desired.

SUMMARY

The following general conclusions may be drawn from this review:

1. The effect of an acid or base upon microbial life processes may be due to the undissociated molecule or any portion of the molecule, in addition to the hydrogen or hydroxyl ions. In addition to affecting the pH, a base or an acid may be used as a nutrient; lime, for example, supplies calcium.

2. Nitrification is one of the main microbial processes in the soil which, almost without exception, positively responds to additions of lime and the resultant increase in soil pH. In general nitrate accumu-

lation will proceed until the soil has a pH of about 4.0; the optimum soil reaction for nitrification is probably between pH 7.0 and 9.0

3. The decomposition of organic residues generally increases with normal additions of lime. This is a favorable situation since it results in a continual release of nutrients, forms additional surface for nutrient retention, improves structure and increases the buffering capacity of the soil.

4. Liming the soil and, therefore, increasing the pH generally increases the population of bacteria and actinomycetes and decreases the fungi.

5. Non-symbiotic nitrogen fixation by most species of *Azotobacter* is favorably influenced by lime up to a pH of about 7.8; *Clostridium pastorianum* has an optimum pH for growth somewhat below that of *Azotobacter*.

6. Symbiotic nitrogen fixation and nodule formation is favorably influenced by liming up to a pH of about 7.0; this optimum may be higher or lower depending on the legume.

7. Insoluble minerals containing nutrient elements, such as iron, magnesium, sulfur, calcium, phosphorus, potassium and manganese are converted into soluble form by both organic and inorganic acids.

8. Certain plant pathogenic organisms have been controlled by adjusting the soil pH into a range in which they either cannot survive or at least are non-pathogenic.

9. It is an accepted fact that the soil is not homogeneous in regard to pH. Therefore, in a soil which, for example, has a measured pH of 6.0, minute loci of alkalinity may exist around calcium carbonate particles or in zones of extremely rapid release of ammonia. In contrast, extremely acid reactions may occur in zones where the microbial processes are resulting in the production of organic and inorganic acids.

This literature review has shown that certain of the soil microbiological processes proceed best in the acid range while others are more effective above pH 7.0. It has also been shown that most microbial activities will take place satisfactorily at a pH of 5.5 to 6.5; this is the range in which the majority of crops yield best. In order to maintain most soils in this range lime is required and should be applied in proper quantities. Remembering, of course, that "lime and lime without manure, (N, P, K etc.) will make both land and farmer poorer."

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Relationship of Liming to Nutrient Efficiency in Soil-Plant Relationships*

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The actual effects of liming on the efficiency with which roots draw upon the supply of nutrients in the soil have been studied only in a broad sense. However, fertile soils have been found to have a large supply of calcium, usually amounting to 50 percent of the cation exchange capacity. In these soils, factors such as clay content, organic matter, structure, pH and moisture supply were such that a maximum yield could be approached without appreciable response from fertilization. These soils must, therefore, have provided the correct nutrient balance and supply to the roots feeding from them. This general observation has been noted on many soils derived from glacial till and from loess. Numerous studies with soils and with solution cultures have been made in an effort to define the unfavorable factors affecting both nutrient efficiency and root vigor in balanced and unbalanced nutrient media. Liming has restored the fertility of many soils with pH values below 5.5 even when the calcium supply was sufficient by soil tests. In other cases, some of which happened in Florida, overliming injury occurred and damage to crop yields and chlorosis of the leaves were reported. Obviously, certain of the nutrients were not sufficiently available to the crops grown in the soil after the heavy lime applications. The relationships that existed in in the soil as a result of the overliming injury and the fertilizer practices at that time have not been studied.

The purpose of this paper is to present the recent data and thinking on the effect of liming on nutrient efficiency in soil-plant relationships. The evidence is gathered from scientific papers dealing with several phases of soil and plant studies.

LIMING AND SOIL ACIDITY

Hydrogen ion concentration.—Soil acidity as measured by soil pH is used commonly as a guide for soil management, including the use of lime. The soil pH measurement, in itself, is found to infer less hydrogen ion concentration than is indicated by titration curves of the soil or from titratable hydrogen leached from the soil with a solution of a neutral salt. The latter methods indicate the presence of hydrogen in the exchangeable form. Calcium, magnesium and potassium are the usual exchangeable bases determined in soil extraction when a neutral salt such as ammonium acetate is used in the leaching of the soil. Many workers calculate the exchangeable hydrogen as the

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difference between the total exchange capacity and the major bases. The hydrogen-by-difference values are used because the assumption is made that manganese, iron, sodium, aluminum and other elements do not contribute appreciably to the exchange complex. This assumption overestimates hydrogen ion on the exchange complex because both sodium and aluminum can be present in relatively high amounts. Sodium in Florida soils occurs where salt water intrusion, salty irrigation water, sodium nitrate in fertilizer, or other sodium salts are added to the soil. Aluminum is likely to be present in all soils and in acid soils it may be a major part of the exchange complex. Obviously, if exchange sites are occupied by secondary or minor elements as well as by the major bases, hydrogen ion must be measured directly rather than calculated by difference.

Soil pH measurements were not the same for soil samples with and without leaching to remove soluble salts (23, 30, 83). Further, Jenny and coworkers (50) questioned the validity of electrometer pH values on the grounds that soil suspensions contain charged particles which might introduce a junction potential of unknown and variable degree where none was assumed. Coleman et al (23) showed that pH values for the supernatant liquid, the sediment and the suspension were the same if 1 N KCl instead of water was used in measuring pH. Schofield and Taylor (72) proposed pH of the soil be determined in M/100 $CaCl_2$ solution. Black (12) stated that the principal value of soil pH measurements is the knowledge they give of associated soil characteristics presumably found by previous correlation studies. Shaw and MacIntire (74) and Shaw (73) recommended that titratable hydrogen be used as an aid in assessing the lime requirement.

Exchangeable aluminum and aluminum toxicity.—Another serious and less recognized aspect of soil acidity is exchangeable aluminum. Earlier work on aluminum in soils was reviewed by Mukherjee et al (62). Marshall (60), Harward and Coleman (41), and Low (58) found that aluminum was exchangeable from clays even after electrodialysis and pure H-clays could be made either by the H-resin method or by leaching with acid. Fiskell et al (32) determined aluminum released from Florida soils by neutral normal ammonium acetate in successive leachings from a column and found aluminum much in excess of the major bases in the soils with pH values in the range 5.0 to 5.5 and somewhat less in soils with pH 6.5 and above.

The role of aluminum in reducing the fertility of acid soils was recognized in 1923 by Burgess (19), who found organic matter and liming more effective than phosphate in controlling soil aluminum solubility and plant intake. The same year Conner and Sears (24) concluded acid soils are toxic to many plants largely because they contain easily soluble aluminum salts. In 1932 Ligon and Pierre (57) and earlier Barnette (9) found that as little as 1 ppm of aluminum in solution culture was toxic to plants grown in solution culture and strongly acid soils contained more than this amount in displaced soil solutions. Vlamis in 1953 (82) displaced the solution from unlimed and limed soils and grew plants on each. These results are shown in Table 1 and illustrate that the cause of poor growth on acid soil extract is aluminum rather than pH, calcium or manganese. Hewitt (45)

identified the effects of excess aluminum and manganese with those due to soil acidity on sugar beet and barley growth; the aluminum injury is most serious in early growth. Bolotina (16) correlated red clover growth and stand with soluble aluminum supply. Aluminum on root surfaces was found to inhibit phosphate intake into the top of plants in studies by Wright and Donahue (86). Pierre et al (67) noted that aluminum solubility in soils rapidly increased below pH 5. Hester (43) observed that vegetables grown on Portsmouth, Bladen and Norfolk soils had lower yields at the pH range where aluminum appeared in the leachate. Abbott and coworkers (1) found that it was necessary to reduce soluble aluminum by liming a dark sandy loam area in the Kankakee area before this soil could be made productive.

TABLE 1.—Growth of Barley in Solutions Displaced from Corresponding Unlimed and Limed Samples of Soil (Vlamis, 1953)*

Substrate	Solution pH	Solution Al	Solution Mn	Barley Yield
		ppm	ppm	mgm
Solution displaced from unlimed soil				
Original solution	4.2	1.8	16.0	139
$Ca(OH)_2$ added	5.8	0.4	12.8	340
NaOH added	5.8	0.4	12.0	286
Solution displaced from limed soil				
Original solution	5.8	0.3	7.6	353
H_2SO_4 added	4.2	0.35	7.4	315
$H_2SO_4 + Al_2(SO_4)_3$ added	4.2	1.8	7.7	176
$H_2SO_4 + MnSO_4$ added	4.2	0.3	16.0	341

*See reference (82).

In 1942 Liebig, Vaneslow and Chapman (56) reported that an apparent stimulating effect of aluminum was in reality a reduction in copper toxicity to Valencia orange and lemon cuttings grown in solution cultures. On soils high in copper this might also be the explanation for apparent response to aluminum additions.

The inhibiting effect of both hydrogen ion (3, 12) and aluminum ion on root growth and therefore on nutrient efficiency requires lime for their control and this may be a major function of lime in soil. However, many other aspects of liming effect on nutrient efficiency are known and are discussed in the next sections.

LIMING AND MINOR ELEMENT AVAILABILITY

Boron.—Where calcium content of plants is abnormally low, boron application has increased the calcium uptake of blue lupines in work by Henderson and Veal (42), also of corn leaves as shown by Fiskell et al (34), and for tomatoes by Brennan and Shive (17). Purvis and

Davidson (68) also pointed out the existence of a functional relationship between boron and calcium in plants and Beckenbach (11) suggested a phosphate-borate relationship. Liming the soil has been found to decrease the water soluble boron level and boron intake by plants which may result in unsatisfactory seed production; this was shown for legumes by Rogers (70, 71), for mustard (53), for yellow lupines (85), and for other crops by Askew (8). The need for boron in the nutrition of symbiotic microorganisms has been determined by Mulder (63) for the nodulation of peas, for nitrogen fixation by *Azotobacter* (52) and the subject was reviewed by Anderson (5). Since liming is the recommended practice for the optimum growth of clovers, the need for additional boron also should be considered.

Iron.—The relation of lime to the absorption of iron by plants has received considerable attention. Allyn (4) contended that liming did not decrease iron intake but increased the deposition of iron at the nodes of corn plants. Iron chlorosis has been observed on calcareous soils for many crops but acid soils, limed heavily and fertilized well, usually do not suffer from a lack of iron in Florida. In a greenhouse experiment, Table 2, the author found that the alkaline silicates released from cement can induce iron deficiency which could be avoided by having ferrous iron in the fertilizer or by spraying with a dilute solution of ferrous sulfate. This might account for iron deficiency in ornamentals near buildings. Other greenhouse studies with heavy liming rates failed to induce iron chlorosis in Lakeland f.s., Scranton f.s., Norfolk or Red Bay f.s.l., using oats as the indicator crop. On high copper soils from the Central Florida Experiment Station farm,

TABLE 2.—Evaluation of Florida Portland Cement Test Product on Lakeland Sand Using Oats as Indicator Crop

Treatment	Soil pH	Oven-dry Weight (Average)		
		1st cutting	2nd cutting	Total
		gms/pot	gms/pot	gms/pot
(1) N, P, K only	6.0	11.0	6.0	17.0
(2) as above with minor elements	5.7	18.8*	8.7**	27.5**
(3) as (2) plus gypsum	5.4	17.4*	11.7**	29.1**
(4) one ton per acre F.P.C. plus N, P, K	7.4	17.6	9.2**	26.8**
(5) 3 tons per acre F.P.C. plus N, P, K	8.2	15.6*C	9.6**C	25.2**
(6) 5 tons per acre F.P.C. plus N, P, K	8.5	9.8C	7.1C	16.9
(7) as (6) plus gypsum and minor elements	8.4	19.0*	9.1**	28.1**
(8) as (4) plus minor elements	7.3	17.1*	10.1**	27.2**
(9) as (5) plus minor elements	8.3	15.0*	9.7**	24.7**
(10) as (6) plus minor elements	8.6	12.7	9.6	22.3*
Least significant difference		4.0*	2.0*	3.4*; 5.8**

*Significant at the 5% level.
** Significant at the 1% level.
C—Identified iron chlorosis.

oats developed iron chlorosis on unlimed soil but not on heavily limed soil or soil treated with 10 lbs. per acre of EDTA or 50 lbs. per acre of frit FN501 or 100 lbs. per acre of Nu-Iron. In soils where heavy metals have accumulated to the extent that root systems are injured, iron EDTA and some other chelates have proven effective both as soil and spray applications (37, 78, 80). In alkaline soils, spray application of ferrous salts or chelates or neutral iron has proven effective (54, 55) and sulfur application has been of temporary benefit. In general, it can be said that liming does not reduce iron availability seriously in crops and indeed may release some of the iron supply immobilized by heavy phosphate applications.

Cobalt.—In Florida the cobalt necessary for cattle is provided in mineral supplements. In New Jersey, liming has been found to reduce the availability of soil cobalt (47) and a species difference was noted for cobalt content. Less than 0.07 ppm of cobalt was found in lucerne which is insufficient for ruminants, but on the same soil other plants were much higher in cobalt content. In soil cultures, Nicholas and Thomas (66) showed that cobalt excess could induce iron chlorosis and phosphate intake by tomato plants. Wright and Lawton (87) noted that in Nova Scotia soils cobalt intake by oats correlated with soil type and pH and was reduced by dolomitic limestone applications.

Copper.—In work by Brown and Hendricks (18), copper deficiency in plants was related to ascorbic acid oxidase, catalase and peroxidase activities lower than normal. Copper toxicity depressed catalase activity, according to Eyster (29). Both copper and zinc have been shown to be fixed by clays (27) and by a chelate mechanism in peat (30). In Australia, McLachlan (61) observed that copper deficient clover was more erect in habit and paler in color than normal clover. On Leon f.s. at the Beef Research Unit near Gainesville, Fiskell (33) found that Ladino clover without copper for four years declined in stand, the leaves were abnormally small and plants were dwarfed in size. Heavy liming intensified these symptoms. In calcareous soils, Boischot and Quillon (15) reported that fixation of copper permitted the presence of large amounts of copper in the soil from Bordeaux sprays without copper toxicity. Fiskell and Westgate (35) studied copper availability in soils in the Sanford area which had grown celery for many years and concluded that liming to pH 6.5 was economically feasible in controlling copper-induced iron chlorosis. The adverse effect of high soil copper on citrus roots has been reported (37, 75). Copper application was necessary on Everglades peat soils to counteract molybdenum toxicity to cattle in studies by Davis (26).

The poisoning of root surfaces (48, 75) by copper and other heavy metals in excess availability results in stunted root systems and interferes with the uptake of other heavy metals and possibly the major elements. Liming corrects this toxicity to a large extent and thereby permits more normal root systems.

Manganese.—Liming long has been recognized and used to reduce manganese availability in acid soils. Manganese has been found to be the least toxic of the heavy metals in producing iron chlorosis (48).

Manganese deficiency has been observed on some crops grown on certain alkaline soils. Manganese fertilization has corrected the deficiency. Examples were reported in the literature for marls from the Homestead area (59) and in Everglades peat having a higher pH (38). The subject has been reviewed by Mulder and Gerretson (65).

In acid Florida soils the manganese status is such that liming normally does not produce a deficiency of this element nor a response to manganese addition. A study on Norfolk loamy fine sand is presented in Table 3 to illustrate the correlations of liming, soil analysis for manganese and manganese uptake by blue lupines that were found four years after the lime was applied. Addition of lime reduces manganese availability and intake; this is not likely to induce manganese deficiency except where the native supply is very low.

TABLE 3.—Manganese in Bitter Blue Lupines and Soil Manganese at Different Liming Rates from Norfolk f.s.l. at North Florida Station
(4 replicates sampled January 15, 1955)

Lime	pH	Soil Manganese		Plant Content
		Exchangeable	Easily Reducible	
tons/acre		ppm Mn	ppm Mn	ppm Mn
0	4.75±.37	17.5±4	84±11	527±63
1	5.22±.15	15.0±4	63± 8	302±31
2	5.59±.12	10.5±4	56± 9	304±29
3	6.28±.17	8.0±4	42± 3	200±60
"F" value		14.97**	9.28**	26.64**
L.S.D. 1% level		5.9	26.3	124
5% level		4.1	18.3	86

Variability between replications is shown.
**Significant at the 1 percent level.

Molybdenum.—For several years molybdenum has been recognized as an essential nutrient. Molybdenum deficiency symptoms of many crops have been identified including "yellow spot" of citrus by Stewart and Leonard (79), "whiptail" in cauliflower and other *Brassica* by Hewitt (46), and other crops by Johnson and coworkers (51). The role of molybdenum was outlined in 1949 by Hewitt (44) as a part of the nitrogen fixation and nitrate metabolism and in water and meristematic relationships tied into abnormal nitrate accumulation. Liming of most soils in Florida was found to release sufficient molybdenum for crops, including clover (36, 40). In some areas of New Zealand and Australia productive clover pasture has resulted from the use of an ounce of sodium molybdate per acre applied in superphosphate (6). For Florida flatwood pastures where calcium values are natively very low, molybdate cannot substitute for a liming program because of the toxicity hazard and the real need for calcium. Other crops not involved in the cattle industry may show occasional molybdenum deficiency on acid soils likely also to be very low in calcium.

Nickel.—Serpentine soils may be infertile due to toxic levels of nickel, and liming is the most satisfactory corrective (25). These soils contain 22 to 61 ppm Ni soluble in neutral normal ammonium acetate. The nickel is held very strongly by soil organic matter in a complex in part replaceable by zinc and by acid solutions. Vergnano and Hunter (81) reported the toxicity limits for oat plants is less than 5 ppm Ni, at which point chlorosis began and later necrosis. Symptoms in the field were like those developed in the solution culture studies and like those resultant from cobalt toxicity.

Zinc.—Little leaf of peach (13), rosette of pecan (2), mottle-leaf of citrus (20), and white bud of corn (10) have been recognized as due to zinc deficiency and are corrected by spraying with zinc sulfate. Wear (84) concluded zinc uptake by sorghum was a pH effect and not a calcium effect. Fiskell (30) reported that zinc accumulations on Everglades peat resulting from the use of Zineb as fungicide were the apparent result of a chelate mechanism. Extraction with nickel and EDTA released the zinc not exchangeable by ammonium salt solutions. At the Beef Research Unit, with ladino clover grown on Leon fine sand limed to pH 6.5, yields have not been significantly different with or without zinc from the treatments receiving all the minor elements (31).

LIMING AND MAJOR ELEMENT AVAILABILITY

The beneficial effect of liming on phosphate intake by plants has been observed on numerous soils. The use of lime for the reduction in phosphate fixation by iron and aluminum has been shown by many workers and a method was proposed by Clark and Peech (22) for the estimation of the phosphate forms. Another procedure for fractionation of soil phosphorus into discrete chemical forms has been developed by Chang and Jackson (21), who found that a highly-weathered soil has the phosphate bound as iron phosphates and less weathered soils as aluminum and calcium phosphates.

The efficiency of liming on nitrogen metabolism is presented in this symposium.

Calcium uptake has been found to have an inverse relationship to potassium uptake from mass action and complementary ion relationships. Other complementary ion effects have been noted for magnesium and sodium effects on calcium uptake.

Cation exchange capacity of roots on a root-area basis was found by Smith and Wallace (76, 77) to correlate well with calcium absorption by orange, beans and barley excised roots; and potassium intake was investigated by Jacobson et al (49).

Epstein (28) found that with young barley roots, about one-fourth the total root volume was involved in the free diffusion of ions from solution into the area of the membrane across which active transport occurs. According to Black (12), the exchange positions on the roots are distinct from the sites involved in active transport of the ions into roots and ions from the soil get to the roots by processes of free diffusion. In such a system liming should play an essential role in the number and kind of ions available for transportation to the roots.

OVERLIMING

The author is discussing overliming because many growers hesitate to lime on grounds that overestimation of the lime requirement might result in crop injury. As shown in the above discussion, liming can reduce the availability of many nutrients. Some years ago overliming of some Florida soils occurred. Two factors at least should be remembered in this connection. One is the fact that little was known about minor elements and secondary element levels in these soils and the other is that fertilizer used was not of the same kind and quantity as the present grades. Thus potassium deficiency and magnesium deficiency were likely to be induced by the heavy liming program. Information on magnesium needs for grapefruit was made available in 1939 (39) and the very low levels present in north Florida soils was reported in 1956 (14). Most growers have become aware of the normal need for both potassium and magnesium. Since boron, manganese and zinc were not used the soils were probably in a depleted state for one or more of these elements and deficiency of one or more of these elements could have occurred. Copper was in use as a fungicide for citrus and vegetable crops, so its supply was ample. Since that time accumulations of the major and minor elements have occurred in soils used for citrus production (69).

Lime-induced iron deficiency and lime-induced manganese deficiency have been discussed. Askew (7) has reported lime-induced boron deficiency. Overliming was found to cause magnesium, zinc, boron and iron deficiency of apple trees in studies by Mulder (63).

To avoid overliming only small increments of lime should be used or the soil should be pretreated with adequate complete fertilization of the soil. Subsequent use of small amounts of secondaries and minors might be necessary in some soils. The use of magnesium salts and a small amount of each minor element applied as salts, suitable frit or other adequate sources is logical, since the soil values are unknown for all these elements. In soils already treated with these elements, need for further additions should prove unnecessary. Where higher liming than usual is to be tried, a small area or strip should be so tested for one year or more before attempting a large scale program. Confidence in an adequate liming program could then replace the ignorance and superstition associated with the use of lime.

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Response of Vegetable Crops to Soil Reaction and Lime

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The liming of acid soils often means the difference between success or failure with many vegetable crops. However, the use of lime with respect to the fundamental nutritional factors involved may mean the difference between an average crop and one that surpasses an average crop in both yield and quality. The emphasis in this paper will be on the interrelated nutritional factors as they are effected by pH variation and the addition of lime.

FUNDAMENTAL EFFECTS OF LIMING

It is obvious that the addition of lime would reduce the soil acidity, and that calcium and sometimes magnesium would be supplied as nutrients. Albrecht and co-workers (1, 2) have concluded that the principal benefit from liming acid soils comes from calcium as a nutrient for plants. Fried and Peech (6) state that gypsum in contrast to lime, fails to improve growth on acid soils and on some soils may result in a decrease in yield. Hewitt (14) has suggested a calcium-manganese and a calcium-aluminum antagonism in plants at a low pH. Schmahl et al (19) found that symptoms of manganese toxicity appeared on alfalfa when the Ca-Mn ratio in the plants was less than 75 although the addition of gypsum to the soil aggravated the manganese toxicity. Arnon and Johnson (3) found that injury to roots was apparent only at a pH of 3 when tomato, lettuce and Bermuda grass plants were grown in cultures ranging from pH 3 to pH 9 in gradations of 1 pH unit. Less calcium was absorbed at a pH of 4 and 5, but the absorption of potassium, magnesium and nitrogen was not affected by a pH from 4 to 9. Growth was reduced at a pH of 9 and was associated with a reduced phosphorus uptake.

It has also been frequently pointed out that nitrification and mycorrhizal activity is impaired in acid soils. Molybdenum becomes more available as the soil pH is increased, and in contrast the availability of other minor elements such as boron, manganese, zinc and iron is decreased as the pH increases. Volk and Bell (20) pointed out that leaching of potassium, ammonia nitrogen, magnesium and calcium was less in slightly acid soil than in highly acid soils. Neller et al (15) found the same to be true with phosphorus. Wallace et al (22) indicated that poor growth of plants, and symptoms associated with low pH, may be the result of combinations of a number of the above-mentioned factors and refers to the condition as a soil acidity complex.

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RESPONSES OF VEGETABLE CROPS IN FLORIDA TO SOIL REACTION AND LIME

The response of vegetable crops to lime has been quite variable in Florida. Beckenback et al (4) reported in 1949 that Bradenton series, soils of a pH range from 5.1 to 6.8, will not respond to liming either in returns from a cash crop or in growth of leguminous or other summer cover. Forsee et al (5), studying fourteen different vegetable crops on soils of the Immokalee and Sunniland series, found that all but sweet corn showed yield increases when the pH was raised to approximately 5.5 to 5.7 and sweet corn showed an improvement in quality and earliness of maturity. Beyond that point the yield response was quite variable. Lima beans and squash were most consistent in their yield decreases past a pH of approximately 5.5 to 5.8. Forsee et al (5) also reported that larger and firmer tomato fruits were produced on limed plots as compared to unlimed but differences were not statistically significant. Tests conducted in commercial tomato fields in the Ruskin area (9) indicate that a better carrying quality of tomato fruits was associated with soils having the larger calcium-supplying capacity. A larger tomato fruit has also been correlated with higher calcium levels in both field and green house experiments (13).

Ozaki et al (17), comparing different liming materials and rates on sandy soils in the Ft. Pierce area, found no significant effects on tomato yields and quality.

Ozaki, C. T. (16) and Ozaki, H. Y. (18) and co-workers, using lower East Coast sandy soils, have reported that blossom-end rot of pepper was decreased by the addition of lime and increased with the application of nitrogen and potash. Indications are that the uptake and utilization of calcium by plants are correlated with the calcium ratio (calcium/total salts) in the soil solution (9, 12). Often the pH or available calcium (by soil test) are not good indications of the calcium-supplying capacity of a soil. A deficiency of soluble calcium or excesses of ammonium, potassium, magnesium or sodium can cause a low calcium ratio in the soil solution, which in turn has been associated with the above-mentioned responses (small fruit and poor carrying quality) and the occurrences of such physiological disorders as blackheart of celery and blossom-end rot of tomatoes and peppers (8, 9, 11, 12). Ammonium ions, in comparison with equivalent amounts of other cations, decreased calcium uptake to the greatest degree. As a result of the studies on these effects of the calcium ratio, the application of a more soluble source of calcium, such as gypsum, is often recommended in addition to lime.

As the total soluble salt concentration increases (with calcium increased proportionately to maintain a constant calcium ratio), the availability of the calcium for assimilation by the plant decreases; thus, in the presence of excess total salts and an apparent adequate calcium level, the above-mentioned plant responses caused by a calcium deficiency, can occur. Foliar applications of calcium, in addition to that supplied by the soil, are also frequently recommended (8, 11, 12).

Volk and Gammon (21) reported in 1952 that nutritional leaf roll of potatoes could be controlled by maintaining a pH of 5.0 to 5.5.

If the pH is low, they recommend that one-fifth to one-third of the fertilizer nitrogen be supplied as nitrate, indicating that leaf roll is associated with a high ammonium nitrate ratio which can be maintained by poor nitrification at a low pH.

EXPERIMENTAL RESULTS

Variation of pH is considered a major factor causing the differential responses of vegetable crops to the source of nitrogen contained in fertilizers. Results of experiments conducted at Bradenton the past four seasons are presented in Table 1. Similar experiments using seven different vegetable crops over a perior of 8 crop seasons, but at one pH level (5.8-6.5), were summarized in a previous report (10).

Tomato yields and quality were reduced (smaller fruit, increased blossom-end rot and a less marketable fruit) when ammonium sulfate was used in plots that had an initial pH of 5.0 to 5.7 (compared to ammonium nitrate or all nitrate sources). As stated above, am-

TABLE 1.—The Effect of pH and Nitrogen Source on the Yields of Tomatoes and Sweet Corn

N Source	Tomatoes (bu./A.) pH 5.8-6.5	Tomatoes (bu./A.) 5.0-5.7	Tomatoes (bu./A.) LSD	Sweet Corn (crates/A.) pH 5.8-6.5	Sweet Corn (crates/A.) 5.0-5.7	Sweet Corn (crates/A.) LSD
Fall 1955						
$NaNO_3$	864	836				
NH_4NO_3	952	952				
$(NH_4)_2SO_4$	896	772				
Total	2712	2560				
Spring 1956						
$NaNO_3$	700	792		240	299	28.2 (NxpH)
NH_4NO_3	776	778		276	301	
$(NH_4)_2SO_4$	724	716		272	280	
Total	2200	2286		788	880	48.9 (pH)
Fall 1956						
$NaNO_3$	272	326		158	268	
NH_4NO_3	538	340		314	338	
$(NH_4)_2SO_4$	330	290		330	342	
$Ca(NO_3)_2$	434	260		194	216	
*$KNaNO_3$	220	178		134	204	
Total	1794	1394		1130	1368	190.8 (pH)
Spring 1957						
$NaNO_3$	822	732		194	259	
NH_4NO_3	960	888	205.4 (NXpH)	253	285	
$(NH_4)_2SO_4$	956	380		251	276	
$Ca(NO_3)_2$	952	774		222	275	
*$KNaNO_3$	1092	898		208	286	
Total	4382	3672	458.2 (pH)	1128	1381	193.5 (pH)

*In the fall of 1956 nitrate of soda potash was used; in the spring of 1957 potassium and calcium nitrate were mixed to obtain the desired ratio.

monium adversely affects the uptake of calcium. Yield and quality of corn were not similarly decreased. In contrast [Table 1 and (10)], when the initial pH range was 5.8 to 6.5, yields and quality of sweet corn, pole beans and cucumbers were reduced when the nitrogen source was all nitrate. Similar but less consistent results were obtained with tomatoes, peppers and cantaloupe. This was especially true when nitrate of soda or nitrate of soda-potash was the source material. Similar, but less consistent results were found when calcium nitrate was used. Calcium plus potassium nitrate has only been used one season and its evaluation should be considered incomplete. Poorest yields and quality were generally associated with the highest or lowest pH plots; the specific nitrogen source and the initial pH level were responsible for the resultant pH. The use of nitrate of soda or nitrate of soda-potash increased the initial pH 0.5 to 1.0 unit; a maximum rise of 0.5 unit was associated with the use of the other all-nitrate sources. With the use of ammonium sulfate the pH decreased 0.5 to 1.0 unit and decreased only slightly with the use of ammonium nitrate. The addition of manganese, iron, molybdenum, boron, copper and zinc in combination (individually and collectively) with the nitrogen-source materials did not alter the described results. This indicates that the high pH had not caused minor element deficiencies. The uptake by the plant of manganese had been reduced (plant tissue analysis), but the reduced uptake did not alter the described results.

Rainfall variation helps to explain seasonal variations in results (Table 1). During a wet season (1956-57), soil nitrification was retarded and a low nitrate-ammonium ratio in all plots tended to alter the effect of the applied source materials accordingly. In comparison, the 1955-56 season was relatively dry and a comparatively higher nitrate-ammonium ratio was maintained. Differences in amount and rate of break-down of organic matter also tends to alter ratios. Organic nitrogen was maintained at a minimum in these experiments.

Comparing the crop yields for one nitrogen source (NH_4NO_3) at the two pH ranges (this eliminates for the most part the described interactions of source material and pH), it can be generally concluded that the larger tomato yields (56-57 crop) were associated with the higher pH range and those of sweet corn with the lower pH range.

Certain complicating relationships or balances between calcium and other nutrients have already been mentioned. In addition, an optimum boron-calcium balance or ratio for best growth has been suggested by a number of research workers (7). In nutrient cultures (12) it has been demonstrated that the higher calcium levels will accentuate a boron deficiency.

Very little has been mentioned about magnesium another major plant nutrient contained in liming materials, such as dolomite. Dolomite is used extensively as a partial and sometimes the sole liming material for Florida vegetable crops. When dolomite is not used as part of the liming material, a soluble source of magnesium is often included in the fertilizer. Deficiencies of magnesium in Florida vegetable crops are rather rare. Sometimes excesses causing a low calcium ratio can occur, for example, when fertilizer magnesium plus dolomite are added to a soil low in native calcium (11).

DISCUSSION AND CONCLUSIONS

Results of experiments on Florida sandy soils indicate that a pH of 5.5 to 6.0 would be desirable for most vegetable crops. However, in many other states and in the Homestead area of Florida, good yields and quality of vegetable crops are obtained where the pH may range from 6.0 to 8.0. Inherently the most productive soils (world wide) are those derived from limestone. The desired results are not only increased yields and quality of crops but also improved animal and human health. It is believed that calcium, more often than most other nutrients, becomes a limiting factor in vegetable production on Florida sandy soils. Lime and other calcium-bearing materials cannot be added indiscriminantly but must be applied with respect to the fundamental nutritional factors involved. The expected beneficial effects are often counteracted by some of the following detrimental effects:

A. Certain minor elements become less available to plants at higher pH or calcium levels.
B. The addition of certain all-nitrate nitrogen sources at higher pH levels has been associated with decreased crop yields and quality.
C. The balance between nutrients (especially calcium to other ions) is of great importance at any pH and the proper ratios must be established and maintained.
D. The use of increased amounts of fertilizer must be accompanied by increased additions of other nutrients to maintain proper nutrient balances, not only to increase yields but to maintain and improve quality.

For a crop such as tomatoes the average yield in Florida is less than 300 bushels per acre. The potential yield should be 1000 to 1500 bushels per acre, a rate that has been reached with greenhouse and hydroponic grown tomatoes and has been approached with field grown crops. In many cases the quality has been improved as much as the yield. In contrast, raising the pH beyond 5.5 to 6.0 has resulted in decreased yields for crops such as corn. Nitrogen has often been determined as a limiting nutrient for corn crops. However, the nitrate source of nitrogen, especially at high pH levels, will be considered as potentially limiting to both yield and quality. With irrigation, sufficient nitrogen (with the above consideration as to source) and adequate plant populations, corn yields can and have been increased to 400-500 crates per acre instead of the average of less than 200.

The above discussion stresses improving the average. However, when crops are grown in soils with a pH of 5.0 to 5.5 or below, some of the following effects (which cause below-average yields and quality) occur:

A. Calcium deficiencies and the leaching of nutrients are more prevalent.
B. Nitrification and mycorrhizal activity are retarded and a low nitrate ammonium ratio tends to accentuate a calcium deficiency.

C. Molybdenum is less available and manganese and aluminum can become toxic.
D. The total effect is best referred to as an acidity complex.

In the final analysis, at the low pH levels, it is a struggle to attain the average; at the higher pH levels, it is a struggle to obtain the maximum. Regardless of whether you are growing tomatoes, corn or peanuts, lime should be used with respect to the fundamental nutritional factors involved.

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The Effect of Lime on Root Distribution

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Of particular interest to farmers is the lack of moisture in the soil during various periods of the year. As a result, increased attention has been given by research workers to factors restricting the growth of roots in subsoils. This has resulted in the study of the effect of deep placement of lime and fertilizers in this acid horizon.

Calcium is well established as an essential element for plant growth. Its influence on growth of plants in general has been studied by many investigators. Some are of the opinion that a prominent function of lime in acid soil is to decrease the solubility of aluminum and manganese in the soil solution (2, 13, 17). It is also well known that calcium will combine with pectic substances to form calcium pectate in the plant. The process of its development in the roots has been more indefinite. As this paper in limited to the influence of calcium upon root distribution, there will be only a brief discussion concerning its effect on other parts of the plant.

Several workers have studied the influence of calcium upon the growth of root hairs (5, 6, 7, 8, 15). Some disagreement has occurred regarding the location and distribution of the pectic and cellulosic substances of root hairs. Cormack (5, 6, 7) is of the opinion that as the root hair develops there is a gradual hardening of the outer pectic layer to calcium pectate which renders them more resistant to distortion. In support of this hypothesis, he conducted a series of experiments using pectic enzymes on the surface cells of living *Brassica* roots. He noted that normal cells had firm definite walls; whereas, in the enzyme treatments some of the cell walls were thin, barely visible and in some cases were completely dissolved. When these roots were placed in a calcium solution, calcium was incorporated into the outer pectic layer of the elongating cell walls and the roots began to develop normally. This illustrates the importance of calcium for proper root development.

Harris (11) noted, while working with peanuts, that when the gynophores or pegs were grown in a cultural medium devoid of calcium and isolated from the root zone, only a few peanuts were formed. This was true even though calcium was added to the root zone of the plants. If calcium was added to the pegging zone there was normal peanut development whenever other factors were favorable. This indicates that calcium may not be translocated from the roots to other plant parts in sufficient amounts for normal development.

A majority of the reported calcium experiments consisted of studies of its influence on the growth of the plant and relatively little attention was made as to its effect on root development. This has been largely due to the difficulty in developing a satisfactory method

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for the study of roots. However, in recent years, increased attention has been given to the influence of lime on root distribution. There have been many observations of deep rooted plants penetrating as far as the plow layer, then apparently turning along the layer instead of growing downward through this region. This led to investigations to find the reason or reasons for this phenomenon although many experiments had been made to study soil acidity and the effect of liming the surface layer of soils. It was noted that the soil immediately below this layer was more acid than the area above. This seemed to indicate that there was insufficient lime in the soil for plant roots to develop properly. Immobility of calcium presented a difficult problem of getting this element into the subsoil prior to the introduction of subsoiling equipment.

There is some disagreement in the literature concerning the benefits of liming the subsoil. Several reports have been made of a favorable response to subsoil applications of lime in the development of the root system (2, 3, 9, 12, 14, 16, 18, 19, 21). However, there has not always been an increased yield with this increase in growth (16, 20). This may be due to variable soil and climatic conditions. At present, the lasting effects of subsoiling appear to be inconclusive.

In reviewing literature concerning the effect of lime on root development, it was not always possible to determine whether increased root development was due to added lime or to fertilizer. Because this discussion is limited to the influence of calcium, the effects of fertilizer will not be reported but will be left to other papers.

The effect of soil reaction on the growth and nodule formation of several legumes has been reported by Bryan (4). He reported that greatest nodule formation appeared to occur at about neutrality. However, they would form at any pH in which the plant would grow. Similar results have been reported by other investigators (11, 12). Albrecht (1) working with soybeans, noted that liberal amounts of calcium were necessary for normal nodulation to occur and that nodules did not form in the absence of calcium.

Increased root development has been reported following the deep placement of lime. Blue et al., (3) noted that deep application of lime on Leon fine sand to 24 inches increased the number of Ladino clover roots in the lower portion of the soil. Robertson et al., (16) have also reported improved root development. Their experiments were with corn grown on Norfolk loamy fine sand.

Englebert and Truog (9) reported that shattering a compacted subsoil had little beneficial effect on the development or penetration of alfalfa roots. However, when lime was incorporated into the subsoil, there was good root penetration. This indicated that subsoil acidity, among other factors, was perhaps the chief cause of poor root development.

It appears that the roots of many deep rooted plants will tend to develop laterally where there is sufficient lime and will not develop laterally where it is insufficient. Pohlman (14) grew alfalfa in sections of tile filled with soil which had been limed at various levels. He reported that over half of the total root weight was in the top 8 inches which had a pH of 6.0. He also found that the small feeding roots were confined largely to the limed areas.

Ferrant and Sprague (10), working with a Sassafras loam, found that the roots of red clover were restricted largely to the limed and fertilized horizons of the soil profile.

Smith et al., (18, 19, 22), while studying the effects of shattering and liming the subsoil, reported that sweet clover roots grew deeply with a limited amount of branching when the subsoils were shattered and limed. They (19) applied 3 tons of lime per acre plus 100 pounds of 0-20-10 to each small grain crop. The crops used were corn, oats with lespedeza, and barley with sweet clover planted every year in a 3-year rotation. Three principal treatments were studied. They were: (1) plowed normally without the subsoil being disturbed; (2) plowed normally with shattering of the subsoil and (3) plowed normally with shattering of the subsoil and the application of 2 tons of limestone and 200 pounds of 8-20-10 fertilizer mixed with the shattered subsoil. When lime was not added to the subsoil, the clover developed several relatively large lateral roots and no normal tap root. The roots did not penetrate the subsoil, but appeared to turn away from it. However, when lime was added to the subsoil, the plants developed normal deep tap roots without large lateral roots and where not winterkilled. The influence of the deep placement of lime on the root development was still quite evident 5 years after the initial treatment. Lime apparently was chiefly responsible for improved root development in the shattered soils since the amount of fertilizer added was small.

The failure of roots to penetrate the acid soil layer may be due to the lack of calcium in which to form the feeder roots of the plant. Stivers et al., (20), conducted a 3-year study on subsoiling, deep lime and deep phosphate applications. They used a strongly acid soil. Approximately 5 tons per acre of limestone was placed in bands 1 and 2 feet apart at an average depth of 14 inches. Superphosphate was applied about 4 inches above the limestone. The plow layer was limed and fertilized. They were unable to find any real differences in the yield of alfalfa, corn, or peanuts on soils that had been chiseled alone or had subsoil applications of limestone. They noted only few roots down to and around the limestone bands and concluded that the volume of roots in this region was too small to influence significantly the growth of the plant. On the other hand, Watenpaugh (21) reported that the yield of alfalfa was definitely correlated with the vigor and depth of root penetration. Alfalfa was grown in a strongly acid soil placed in 14-by-21-inch sewer tile. The treatments of the subsoil were no lime, one fourth and one half lime requirement. The surface 3 inches were treated with one half and full lime requirement plus phosphorus and potash. It was found that root development was correlated with the pH and the exchangeable calcium of the various layers. He noted that nearly all root growth was stopped at a pH of 4.8 and that as the pH was increased toward neutrality root development became more vigorous.

Other workers who have noted beneficial effects of lime placement on root development are Longenecker and Merkle (13). They conducted a series of pot experiments on the influence of lime placement on crimson clover root development. They used on acid soil with a pH of 4.0 for the experiment. The soil was low in exchangeable nutrients but high in soluble aluminum and manganese. Each pot was

filled to a depth of 9 inches with soil. All pots were fertilized with nitrogen, phosphorus, potassium and magnesium. The treatments were as follows:

1. The entire pot fertilized but unlimed.
2. The entire pot fertilized and limed.
3. The entire pot fertilized. The soil on one side of the pot was limed and that on the other side left unlimed.
4. The entire pot fertilized, only the top 3 inches limed.
5. The entire pot fertilized, only the top 6 inches limed.
6. Only the lower 6 inches fertilized and limed.
7. Only the top and bottom 3 inch layer fertilized and limed.
8. The entire pot fertilized and areas 2 inches in diameter and 1 inch deep around each seed were limed.

They noted that the development of fibrous roots was restricted largely to the limed zone. In the split pot, treatment number 3, there was good root growth in the limed side and almost no growth in the unlimed portion. When the surface 3 inches and lower 3 inches were limed, abundant fibrous roots developed in the treated areas. These roots were connected by strands, devoid of fibrous roots, through the middle acid region. This indicated that primary roots may extend through unfavorable conditions but that fibrous root development is dependent upon the more favorable conditions brought about by the addition of lime.

SUMMARY

The failure of roots to penetrate the acid subsoil has resulted in an increased study of deep placement of lime on root development. A review of the literature was made concerning the effect of calcium on root distribution.

Results indicate that: (a) calcium is essential for proper root development. Without this element, cells do not form firm definite walls; (b) calcium is necessary for normal nodulation of legumes; (c) deep application of calcium increased the number of fibrous roots in the limed portion of the soil; (d) higher yield did not always accompany increased root development; (e) the period of effectiveness of deep placement of lime has not been determined.

It is apparent from the above literature review that some disagreement exists on the value of subsoiling and deep lime placement. It appears that existing environmental conditions influence greatly the results obtained. Therefore, additional research is needed before more definite answers can be given.

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Effect of Lime on Some North Florida Soils*

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Any good textbook dealing with soil fertility will explain the functions of calcium and magnesium, the constituents of lime, for growing cultivated crops. Crops vary in their lime requirements. Peanuts take from the soil approximately 100 pounds per acre of calcium to produce a ton of nuts (8), while a crop of corn yielding 60 bushels per acre takes up approximately 40 pounds per acre (1, 7). The requirements of soybeans probably lie between these values. On Florida soils where calcium and magnesium are low, yield responses are usually greater for those crops that require the larger amounts. However, there are crops that often give no yield responses when soil tests show that exchangeable calcium and magnesium are present in amounts lower than the crop harvested contains; for example, corn. This may be associated with the root system and the ability of the plant to take up calcium and magnesium in forms other than exchangeable. This may also be due to the soil test methods currently in use which may give low values for exchangeable calcium and magnesium when soils are high in certain elements (4).

Yield response to lime may not be directly related to calcium and magnesium nutrition of the plants but rather to the effect of these elements on other nutritional elements or factors.

In many cases lack of response may be related to placement of lime. On soils with plowsoles or hard pans, deep placement of lime provides a balanced nutrition in the subsoil which permits a deeper root system and a larger reservoir of water (10).

It is the purpose of this paper to summarize the data from the experiments in north and west Florida for corn, peanuts, soybeans and oats, where lime has been a variable. Soil analyses and crop yields will be used to measure responses.

METHODS

The experiments were located on Red Bay fine sandy loam at the West Florida Station near Jay; Ruston fine sandy loam at Mobile Unit No. 3 near Mariana; Norfolk loamy fine sand at North Florida Station near Quincy; and Klej fine sand at Suwannee Valley Station near Live Oak.

On the Red Bay fine sandy loam the effects of lime were determined in four experiments as follows: rates of lime on a three-year rotation, source of phosphorus, source of nitrogen and a 5 x 5 x 5

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factorial on a two-year rotation. The first experiment was designed to test the effects of 0, 1000, 2000 and 4000 pounds of dolomitic lime on a three-year rotation consisting of lupines plowed down followed by corn the first year, oats for green manure followed by peanuts the second year and oats for grain followed by soybeans the third year. The second and third experiments compared 12 sources of phosphorus with check and 6 sources of nitrogen, with check with and without lime, on a three-year rotation similar to that in experiment one. The fourth experiment was a factorial of 5 levels each of nitrogen, phosphorus and potash on a two-year rotation consisting of lupines plowed down for corn the first year and oats plowed down as a green manure crop for peanuts the second year. Experiments one, two and three contained 4 replications of each treatment arranged in randomized block, split plot and split plot designs respectively. The fourth experiment had only one replication. Treatments were arranged in 5 blocks by sacrificing one degree of freedom for the second order interaction. The treatments of experiments two, three and four are described fully in previous publications (5, 6, 11).

On the Ruston fine sandy loam 0, 2000, 4000 and 8000 pounds per acre of dolomitic lime were applied to a two-year rotation consisting of lupines plowed down for corn the first year and oats for green manure plowed down for peanuts the second year. Four replications of each treatment were arranged in a randomized block design.

Response to lime was tested in two experiments on Norfolk loamy fine sand. The first experiment was for the purpose of comparing the effects of 0, 2000, 4000 and 8000 pounds per acre of dolomitic lime on a three-year rotation in a manner similar to that described for the lime on rotation experiment on Red Bay fine sandy loam above. The second experiment was a continuous crop and rotation experiment. The lime variable was introduced into this experiment at the end of 6 years. Soil tests indicated that the pH and exchangeable calcium were decreasing on the continuous peanut plots more than on plots where peanuts were grown less frequently. Plots were split and dolomite was applied at the rate of one ton per acre to half the plots. After this the experiment was continued for four years. An outline of the treatments has been reported (13).

On the Klej fine sand three experiments had lime as a variable. These were: lime on rotation, fertility on rotation and minor elements on rotation experiments. The first experiment was to compare the effects of 0, 1000, 2000, 4000 and 8000 pounds of dolomite and high calcic lime on a two-year rotation similar to that on Ruston fine sandy loam. The treatments for the second experiment consisted of a factorial arrangement of 3 rates each of nitrogen, phosphorus and potash and a check treatment on a three-year rotation similar to that used in the lime on rotation experiment on Red Bay fine sandy loam. All treatments had lime applied to half the plots. The third experiment compared the effects of 7 minor elements with a check treatment all with and without lime.

In the experiments described above the effects of lime were tested on a rotation because there are disadvantages in growing most crops continuously, especially peanuts and corn (9, 13). All crops in the rotations received the treatments. This was done either by including

all crops in each treatment block or by having a block containing all treatments for each crop and rotating the crops back and forth between areas.

In the experiments where rates of lime were tested on corn, nitrogen was usually supplied at rate of 100 pounds per acre of N, forty percent was applied at planting time and the balance when the corn was knee high. Potassium was applied at the rate of 100 pounds per acre of K_2O from muriate of potash at planting time. Phorphorus was applied at the rate of 75 pounds per acre P_2O_5 from superphosphate at planting time, except on the Red Bay fine sandy loam, where the rate for the first year was approximately 3 times this amount.

In these same experiments peanuts received approximately 400 pounds per acre of 0-14-10 fertilizer, lupines or vetch 300 pounds per acre of 0-14-10, oats 500 pounds per acre of 4-10-7 and soybeans 400 pounds per acre of 4-12-12.

TABLE 1.—Yield Response to Lime on Red Bay Fine Sandy Loam.

Year	lbs./A. of dolomite				L.S.D.	
	0	1000	2000	4000	5%	1%
			Corn (bus./A.)			
1950	62.2	60.8	59.0	61.6	N.S.	
1951	60.1	56.2	61.0	61.3	N.S.	
1952	23.9	21.7	19.9	19.7	N.S.	
1953	58.9	59.9	60.8	68.0	N.S.	
1954	46.5	44.7	51.5	51.0	N.S.	
1955	55.3	56.7	62.0	57.3	N.S.	
Ave.	51.2	50.0	52.4	53.2		
			Peanuts (lbs./A.)			
1950	1800	1490	1680	1590	N.S.	
1951	1110	1210	1230	1130	N.S.	
1952	1110	1100	1210	1200	N.S.	
1953	1450	1490	1430	1630	180	N.S.
1955	1730	1630	1920	2120	240	N.S.
Ave.	1440	1380	1490	1530		
			Soybeans (bus./A.)			
1950	17.5	18.8	20.8	19.8	N.S.	
1952	25.0	27.6	28.0	28.7	N.S.	
1953	20.2	22.3	22.0	23.7	N.S.	
1954	11.5	11.9	11.2	11.8	N.S.	
1955	20.5	23.1	27.1	27.3	N.S.	
Ave.	18.9	20.7	21.8	22.3		
			Oats (bus./A.)			
1951	45.9	43.5	44.4	46.2	N.S.	
1952	11.2	8.2	11.7	9.7	N.S.	
1953	40.9	39.4	40.1	38.9	N.S.	
1954	26.5	32.6	34.6	38.0	N.S.	
1955	24.8	20.5	25.6	20.8	N.S.	
Ave	29.9	28.8	31.3	30.7		

It would take too much space to go into detail concerning rates of fertilization and treatments for the 5 x 5 x 5 factorial, the source of nitrogen and source of phosphorus experiment on the Red Bay fine sandy loam, the continuous crop and rotation experiment on the Norfolk loamy fine sand and the fertility on rotation and minor elements on rotation experiments on the Klej fine sand. These experiments are similar, since the lime variable is introduced using the split plot technique. Part or all of the data for all but the minor element experiment on Klej fine sand have been reported (5, 6, 11, 12). In those where only part of the data are reported, the treatments and other particulars are explained fully. The minor element experiment on the Klej fine sand compares with that on the Red Bay fine sandy loam (6).

Dixie 18 corn, Dixie Runner peanuts, Jackson, Roanoke or Lee soybeans and Southland or Floriland oats were planted. The varieties of soybeans or oats depended on the variety's adaptation to the area for a particular season.

Yields of the cover crops were usually taken and they generally responded to lime, but since it was felt that this response would be reflected in the crop that followed, data for these crops are not reported. Lupines were replaced by vetch since 1955 in all experiments because disease affected them adversely.

Surface soil samples were taken every two years from all experiments and profile samples approximately every four years. Calcium, pH, magnesium, potassium and phosphorus determinations were made. Calcium, magnesium and potassium were extracted with ammonium acetate buffered at pH 4.8. Calcium and potassium were determined on the Beckman DU spectrophotometer using the Hydrogen flame. Magnesium data were obtained using the modified colorimetric method described by Carver and Robertson (4). Phosphorus was extracted with .03 N NH_4F in .1 N HCl using 10 parts extractant to 1 part soil (3) because this method gave values that correlated with available phosphorus (12).

RESULTS AND DISCUSSION

Red Bay Fine Sandy Loam:

The rates of dolomite applied to the lime on rotation experiment were 0, 1000, 2000, and 4000 pounds per acre. This gave pH values 5.1, 5.3, 5.5 and 5.8 units, respectively. The corresponding exchangeable calcium values were approximately 160, 250, 420 and 600 pounds per acre. The corn, peanut, soybean and oat yield data for the lime on rotation experiment are shown in Table 1. Lime did not increase corn yields significantly for any of the years, but the average of data for 6 years indicated that 4,000 pounds per acre of dolomite gave 2 bushels more corn than the unlimed soil. This and data later reported from other experiments on this soil were evidence that 4000 pounds per acre of dolomite was probably too low for optimum yields. The low yields for 1952 were due to dry weather.

Peanut yield differences for lime were significant in 1953 and 1955. With the exception of 1950, lime increased the yields every year but

TABLE 2.—Yield Response[1] to Lime in Source of Phosphorus and Nitrogen Experiments on Red Bay Fine Sandy Loam.

Year	Corn (bus./A.)			Peanuts (lbs./A.)			Soybeans (bus./A.)			Oats (bus./A.)		
	Limed[2]	Unlimed	Increase	Limed[2]	Unlimed	Increase	Limed[2]	Unlimed	Increase	Limed[2]	Unlimed	Increase
Source of Phosphorus Experiment												
1950[3]	59.4	57.2	2.2*	1750	1630	120*	15.0	13.3	1.7*	-----	-----	----
1951	63.9	61.8	2.1	940	830	110*	10.7	8.9	1.8**	73.5	74.8	-1.3
1952[3]	32.5	32.5	0.0	1390	1000	390**	15.8	11.9	7.5**	-----	-----	
1953	67.7	55.9	11.8*	1340	1100	240**	23.1	19.6	3.5**	44.4	44.3	0.1
1954	43.2	40.7	2.5*	1210	980	230**	10.4	8.6	1.8**	53.4	40.4	13.0**
1955	48.4	43.4	5.0*	1730	1440	290**	20.9	15.5	5.4**	13.8	11.7	2.1**
Ave.	52.5	48.6	3.9	1390	1160	230	16.7	13.0	3.7	46.3	42.8	3.5
Source of Nitrogen Experiment												
1950[3]	62.5	64.9	-2.4	1990	2060	-70	13.2	10.2	3.0	-----	-----	
1951	74.9	70.2	4.7	950	940	10	15.6	11.7	3.9*	61.1	63.4	-2.3
1952	29.2	26.4	2.8	1520	1530	-10	23.5	20.5	3.0*	62.3	62.5	-0.2
1953	73.6	67.5	6.1**	1480	1270	210**	22.9	20.9	2.0*	39.9	40.5	-0.6
1954[3]	41.7	37.7	4.0*	-----	-----	-----	-----	-----	-----	-----	-----	----
Ave.	56.4	53.3	3.1	1480	1450	30	18.8	15.8	3.0	54.4	55.5	-1.0

[1]One and two asterisks indicate significance at the 5% level and 1% level of probability respectively.

[2]Limed plots received 2000 lbs./A. of dolomite in fall of 1949 and an additional 3300 lbs./A. in spring of 1952. The unlimed plots averaged 5.1 pH units and the two lime applications increased the pH to 5.4 and 6.1 respectively.

[3]Oats were not planted in fall of 1949 and were injured by frost on the source of phosphorus experiment in 1952. All crops but corn were discontinued in the source of nitrogen experiment in 1954.

the reversal for 1950 was large enough to make the average lime response for the 5 years reported only 90 pounds per acre.

There was an increase in soybean yields for lime every year and the averages showed a consistent yield increase for increasing lime levels. However, differences were not significant at the 5 percent level of probability for any of the years.

The oat yields were generally low and differences were not significant.

Table 2 shows the lime response in the source of phosphorus and source of nitrogen experiment. In these experiments the limed plots received a total of 5300 pounds of dolomite per acre. A ton was applied at the beginning of the experiment and the balance in the spring of 1952. The data indicate that the second application of lime generally gave larger corn, peanut and soybean yield increases than when only one ton of lime was applied. Oats gave the poorest response to lime.

The 5 x 5 x 5 x 2 factorial experiment had the same pH differential for lime as the source of nitrogen and phosphorus experiments. This experiment had 250 plots for corn and 250 for peanuts each year. The results from the lime applications are shown in Table 3. Differences for lime on corn were significant every year and on peanuts all but the first year. As in the preceding two experiments, the largest yield differences resulted from the second application of lime in 1952. Dry weather in 1952 lowered yields to a point where large differences were impossible.

TABLE 3.—Yield Response to Lime in 5 x 5 x 5 x 2 Factorial Experiment on Red Bay Fine Sandy Loam.

Year	Corn (bus./A.)			Peanuts[1] (lbs./A.)		
	Limed[2]	Unlimed	Increase[3]	Limed[2]	Unlimed	Increase[3]
1950	52.3	51.1	1.2**	1580	1540	30
1951	55.5	52.6	2.9**	1210	1090	110**
1952	20.9	19.5	1.4**	1830	1740	90**
1953	46.9	38.8	8.1**	1660	1470	180**
1954	42.7	36.2	6.5**	1550	1430	120**
1955	38.3	32.7	5.6**	------	------	
1956	52.9	45.5	7.4**	------	------	
Ave.	44.2	39.5	4.7	1570	1450	120

[1]Peanut plots discontinued in 1955.

[2]The limed plots had the same lime treatment as those in source of nitrogen and phosphorus experiments.

[3]One and two asterisks indicate significance at 5% and 1% level of probability respectively.

Ruston Fine Sandy Loam:

Chemical data from surface soil samples taken in 1957 are shown in Table 4. Lime had no effect on phosphorus and very little on potassium. It increased the pH from 5.2 to 7.4, the calcium from 130 to 300 pounds per acre and the magnesium from 30 to 240 pounds per acre.

TABLE 4.—Chemical Analyses Data of 1957, 0-6" Soil Samples from Ruston Fine Sandy Loam.

Determination*	lbs./A. dolomite 0	2000	4000	8000
pH	5.2	5.5	5.8	7.4
P_2O_5	790	860	850	770
K_2O	120	140	140	140
Ca	130	170	280	300
Mg	30	40	50	240

*P_2O_5, K_2O, Ca and Mg expressed in lbs./A.

The yield data from Ruston fine sandy loam in Table 5 show no consistent yield response for lime with either corn or peanuts. It appeared that the soil contained sufficient calcium and magnesium for these crops. The calcium values reported in Table 4 were determined by the use of the flame spectrophotometer. When calcium was determined chemically it was found that the untreated surface soil contained a total of 800 pounds per acre of calcium, of which 550 pounds per acre were exchangeable.

TABLE 5.—Yield Response to Lime on Ruston Fine Sandy Loam.

Year	lbs./A. of dolomite 0	2000	4000	8000	L.S.D. 5%	1%
		Corn (bus./A.				
1951	74.2	74.1	74.2	74.2	N.S.	
1952	25.5	24.1	22.2	21.5	N.S.	
1953	62.1	63.6	66.0	65.8	N.S.	
1954	70.2	66.3	66.3	67.3	N.S.	
1955	35.5	34.5	36.3	28.1	N.S.	
1956	73.7	69.5	67.3	76.1	6.0	N.S.
1957	73.1	75.0	78.9	83.9	3.2	4.5
Ave.	59.2	58.1	58.7	59.6		
		Peanuts (lbs./A.)				
1951	1920	2000	1990	1890	N.S.	
1952	1600	1600	1500	1550	N.S.	
1953	1670	1740	1720	1540	N.S.	
1954	960	940	940	870	N.S.	
1955	1960	1990	2020	1820	N.S.	
1956	1760	1710	1770	1690	N.S.	
1957	2210	2270	2220	2420	N.S.	
Ave.	1720	1750	1740	1680		

Norfolk Loamy Fine Sand:

Chemical data from soil samples taken from the lime experiment on Norfolk loamy fine sand are reported in Table 6. The lime in-

creased the pH from 5.4 to 6.6, had no effect on the level of phosphorus, improved the retention of potash, and increased the calcium from 147 to 772 pounds per acre and the magnesium from 30 to 188 pounds per acre.

TABLE 6.—1956 Chemical Analyses Data for 0-6" Samples from Norfolk Loamy Fine Sand.

Determination*	lbs./acre dolomite			
	0	2000	4000	6000
pH	5.4	6.2	6.3	6.6
P_2O_5	450	560	490	460
K_2O	82	92	93	114
Ca	147	409	581	772
Mg	30	101	134	188

*P_2O_5, K_2O, Ca and Mg in lbs./A.

Table 7 contains 11 years' yield data for rates of lime on corn and peanuts, 10 years for oats and 2 years for soybeans. The 6000 pounds per acre application raised the pH to 6.5 and the available calcium to 850 pounds per acre, approximately.

Although yield differences for lime on corn were significant only in 1949, 1950 and 1957, the data indicate that the first level (2000 pounds per acre) gave yield increases 9 out of the 11 years. The average shows an increase for the first level but no additional increase for the second and third levels. It is also noticed that differences are small when yields are low. The low yields are correlated with moisture conditions.

The peanut yield differences were significant 5 out of 11 times. In 1947, 1952, 1954 and 1957 yields increased with increasing rates of lime but in 1948 the response was negative. As in the corn data, the first rate (2000 pounds per acre) gave the best increase. Additional lime tended to decrease yields.

The oat data showed significant yield differences only once in 10 years and the averages of all years were inconsistent. This corresponds with the data for oats on Red Bay fine sandy loam.

Lime gave significant yield increases both years for soybeans but, as above for corn and peanuts, the best results were obtained for the 2000 pounds per acre application.

The chemical data shown in Table 6 were obtained from samples following corn. In 1957 all plots were sampled and averages of all the data were presented in Table 8 to show the effect of crops on these values. The pH, magnesium, calcium and potash values were lower following peanuts and soybeans than corn.

The four years' yield data for corn and peanuts from the continuous crop and rotation experiment on Norfolk loamy fine sand show yield increases for lime every year. These data are averages of 17 treatments. Corn and peanuts were grown continuously and in two and three-year rotations. As mentioned previously, the experi-

TABLE 7.—Yield Response to Lime on Norfolk Loamy Fine Sand.

Year	lbs./A. of dolomite 0	2000	4000	6000	L.S.D. 5%	1%
			Corn (bus./A.)			
1947	39.3	41.4	41.5	40.1	N.S.	
1948	41.4	45.3	42.2	43.6	N.S.	
1949	78.2	81.9	82.4	84.7	6.1	N.S.
1950	98.5	100.8	105.2	103.2	4.5	N.S.
1951	69.4	74.3	69.2	70.9	N.S.	
1952	36.1	38.5	39.0	37.5	N.S.	
1953	75.8	82.1	81.1	82.7	N.S.	
1954	43.4	42.7	43.0	40.2	N.S.	
1955	64.3	62.3	64.3	62.0	N.S.	
1956	66.8	72.4	70.2	71.1	N.S.	
1957	60.7	68.8	69.5	70.7	5.2	N.S.
Ave.	61.3	64.6	64.3	64.2		
			Peanuts (lbs./A.)			
1947	1630	1890	1910	1990	210	300
1948	1760	1660	1530	1520	158	N.S.
1949	1100	1130	1000	1100	N.S.	
1950	1650	1630	1610	1640	N.S.	
1951	1910	2350	2120	2020	N.S.	
1952	1370	1780	1290	1520	330	N.S.
1953	1450	1550	1560	1370	N.S.	
1954	1580	1910	1970	1930	280	N.S.
1955	1560	1450	1590	1680	N.S.	
1956	700	1550	1640	1470	N.S.	
1957	910	1030	1080	1140	160	
Ave.	1510	1630	1570	1580		
			Oats (bus./A.)			
1948	21.1	25.0	23.2	23.1	N.S.	
1949	17.0	17.3	18.0	24.6	N.S.	
1950	30.8	29.8	27.9	24.0	N.S.	
1951	79.4	77.4	88.5	76.2	N.S.	
1952	63.9	59.1	53.3	46.4	N.S.	
1953	50.4	50.5	46.5	45.0	N.S.	
1954	26.2	27.1	31.5	34.6	N.S.	
1955	23.7	23.6	20.2	21.4	N.S.	
1956	21.6	21.9	29.9	30.4	7.4	N.S.
1957	39.0	31.7	31.4	25.7	N.S.	
Ave.	37.3	36.3	37.0	35.1		
			Soybeans (bus./A.)			
1956	26.5	30.6	30.8	29.5	4.8	N.S.
1957	21.6	28.6	31.4	31.0	4.8	6.6
Ave.	24.0	29.6	31.1	30.2		

ment had been in progress 6 years before the lime variable was introduced. Where peanuts were in the rotations the level of calcium was reduced in the soil. Continuous peanuts had lower calcium than the two-year rotation, which was in turn lower than the three-year rotation (9, 13). This meant that the average available calcium for

TABLE 8.—Effect of Crops on 1957 Chemical Data from Norfolk Loamy Fine Sand.

Determination*	Soybeans	Following Peanuts	Corn
pH	5.4	5.5	5.9
P_2O_5	560	600	490
Mg	120	100	170
Ca	310	290	360
K_2O	130	90	126

*P_2O_5, K_2O, Ca and Mg in lbs./A.

the rotation experiment at the end of 6 years was lower than the zero treatment in the lime on rotation experiment which had been carried on at the same time, since in this experiment lime was tested on a three-year rotation. For this reason, when one ton of lime was applied to half the plots in the continuous crop and rotation experiment it gave a somewhat lower pH, calcium and magnesium values than existed for the zero and one ton of lime treatments in the lime on rotation experiment. The data in Table 9 confirm this, since yield increases for lime on corn and peanuts occur every year and are larger than those for the lime on rotation experiment (Table 7).

TABLE 9.—Yield Response to Lime[1] from Rotation Experiment on Norfolk Loamy Fine Sand.

Year	Corn (bus./A.) Limed	Unlimed	Increase[2]	Peanuts (lbs./A.) Limed	Unlimed	Increase[2]
1954	39.7	38.4	1.3	1420	1100	320**
1955	52.1	50.9	1.2	1790	1720	70**
1956	58.8	55.0	3.8**	1260	1010	250**
1957	69.1	48.5	20.6**	920	720	200**
Ave.	54.9	48.2		1350	1140	210

[1]One ton of high calcic lime was applied to half the plots in spring of 1954. 1957 prefertilization samples showed pH on limed and unlimed plots to be 5.4 and 5.0 respectively.

[2]Two asterisks indicates significance at the 1% level of probability.

Klej Fine Sand:

The lime on rotation experiment was started in 1957 on a two-year rotation. The pH range and corn yield data are reported in Table 10 for 1957. The unlimed plots have practically no exchangeable calcium. The high calcic lime gave a wider range of pH values than the dolomite. The high calcic lime did not improve corn yields as much as dolomite because in this soil magnesium is also deficient (2).

TABLE 10.—Yield Response to Dolomite and High Calcic Lime on Klej Fine Sand.

Dolomite (lbs./A.)	pH	Corn Yield (bus./A.)	High Calcic Lime (lbs./A.)	pH	Corn Yield (bus./A.)
0	5.2	41.9	0	5.0	15.6
1000	5.4	49.6	1000	5.8	10.2
2000	6.2	50.9	2000	5.9	17.5
4000	6.2	55.6	4000	6.4	15.0
8000	6.5	57.7	8000	6.9	23.1
L.S.D. 5%		6.2			N.S.
L.S.D. 1%		8.8			

Table 11 contains data from the minor element on rotation experiment. In this experiment high calcic lime (ground marble) was used and did not increase corn yields as much as would be expected since calcium was so low. As pointed out previously, this was probably due to the lack of magnesium. The peanut data show large yield increases for lime every year and the average yield increase is almost 800 pounds per acre. The low yields in 1957 are attributed to too much rain which rotted the pegs and increased losses before maturity.

TABLE 11.—Yield Response to Lime[1] from Fertility Experiment on Klej Fine Sand.

Year	Limed	Unlimed	Increase[2]	Limed	Unlimed	Increase[2]
	Corn (bus./A.)			Peanuts (lbs./A.)		
1954	35.7	34.9	0.8	1330	760	570**
1955	26.4	23.5	2.9	1760	1390	370**
1956	27.2	21.0	6.2**	1840	1040	800**
1957	26.6	12.4	14.2**	430	210	220**
Ave.	29.0	23.0	6.0	1340	850	490

[1]Limed plots received 1 ton of high calcic lime in spring of 1954 and an additional ton of dolomic lime in spring of 1957. The first ton increased the pH from 4.9 to 5.4 and the second ton from 5.4 to 6.0.

[2]Two asterisks indicate significance at the 1% level of probability.

The data from the fertility on rotation experiment are reported in Table 11. The corn data clearly show the need for magnesium. The high calcic lime application in 1954 did not increase the yields significantly, but after the ton of dolomite was applied in 1956 yield differences were highly significant. The increase for lime on peanuts was not as great for 1954 and 1955 as in the minor element experiment reported in Table 12. The lime used in this experiment was coarser and less available than that used in the minor element experiment. The yield difference was greater when the ton of dolomite

was added to the limed plots in the spring of 1956. The low yields in 1957 were attributed to wet weather as already mentioned.

TABLE 12.—Yield Response to Lime[1] from Minor Element Experiment on Klej Fine Sand.

Year	Limed	Unlimed	Increase[2]	Limed	Unlimed	Increase[2]
	Corn (bus./A.)			Peanuts (lbs./A.)		
1954	43.5	40.4	3.1	2010	740	1270**
1955	19.6	19.7	-0.1	1710	1070	640**
1956	32.4	30.6	1.8	2610	2140	470**
1957	36.2	27.5	8.7**	860	160	700
Ave.	32.9	29.6	3.3	1800	1030	770

[1]Limed plots received 1 ton of high calcic lime in spring of 1954 and an additional ton in spring of 1956. pH increased from 4.9 to 5.6 for the first ton and from 5.6 to 6.1 for the second.

[2]Two asterisks indicate significance at the 1% level of probability.

Soil Analyses:

Table 13 shows what effect lime had on the pH, calcium and magnesium in the profile of the four soils. Liming affected the pH and calcium content of the Red Bay fine sandy loam, the Ruston fine sandy loam and the Klej fine sand to a depth of 18 inches. It increased the magnesium on the Ruston fine sandy loam and Norfolk loamy fine sand to the 30 inch depth. Magnesium moved down considerably more than calcium. The calcium values from the Klej fine sand are not high enough to account for the two tons of lime applied. This soil is high in phosphorus, which interfered with the method used to determine the calcium. Values obtained using the chemical method were approximately three times as high.

CONCLUSION

Experiments were conducted for periods up to 11 years to test the value of lime on Red Bay and Ruston fine sandy loams, Norfolk loamy fine sand and Klej fine sand. The effects of the lime on the chemical properties of the soil and corn, peanuts, soybeans and oat yields were used as measures of response.

On Red Bay fine sandy loam where exchangeable calcium was high in the surface but low in the subsoil, rates of dolomite up to 4000 pounds per acre increased the pH from approximately 5.3 to 5.8 but had no consistent effect on crop yields. An application of 5300 pounds per acre of dolomite, however, gave highly significant corn, peanut and soybean yield increases most years but had little effect on oat grain yields.

The Ruston fine sandy loam had 0, to 8000 pounds per acre of dolomite applied. This increased the pH from 5.2 to 7.4 but the

TABLE 13.—Effect of Lime* on pH, Ca, and Mg Values on Profile Samples.

	Red Bay f.s.l.				Ruston f.s.l.						Norfolk l.f.s.						Klej fine sand					
	pH		Ca		pH		Ca		Mg		pH		Ca		Mg		pH		Ca		Mg	
	L	UL	L	UL	L	UL	L	UL	L	UL	L	UL	L	UL	L	UL	L	UL	L	UL	L	UL
0-6″	6.2	5.3	830	160	7.8	5.2	840	130	350	30	6.5	5.0	850	70	180	20	6.2	5.2	285	22	41	13
6-12″	5.4	5.1	110	70	5.8	5.2	280	170	200	20	6.5	5.0	320	30	110	10	5.8	5.1	75	16	19	8
12-18″	5.3	5.1	100	80	5.6	5.5	220	280	120	30	6.0	5.0	230	50	120	10	5.2	4.9	16	14	7	8
18-24″	5.2	5.1	90	90	5.6	5.7	350	290	100	30	5.9	5.3	230	290	210	30	5.1	5.0	8	12	4	8
24-30″	5.1	5.1	90	90	5.6	5.7	460	340	70	40	5.8	5.4	200	310	260	70	----	----				

*Red Bay f.s.l and Klej f.s. data are taken from fertility experiment and are averages of all treatments. The Ruston f.s.l. and Norfolk l.f.s. data are taken from the lime experiment and are averages of the zero or unlimed plot and the highest level of application which was 8000 and 6000 lbs./A. of dolomitic lime respectively.

averages of 7 years' data for corn and peanuts showed no consistent yield differences.

The lime experiment on Norfolk loamy fine sand had rates of 0, 2000, 4000 and 6000 pounds per acre of dolomite. This gave a pH range from 5.4 to 6.6. Eleven years' data showed in general that 2000 pounds per acre increased corn, peanut and soybean yields but had no consistent effect on oat yields. Applications above 2000 pounds per acre had little effect on yield.

The Klej fine sand had the least available calcium of the soils tested. Magnesium was also low. High calcic lime increased peanut yields but had little effect on corn. Peanut yields were tripled in some cases. Dolomitic lime did not give as large a response as the high calcic lime on peanuts but was more effective on corn. Corn apparently needed more magnesium for good growth than the soil contained.

Soil test data indicated that peanuts reduced pH, calcium and magnesium more than corn or soybeans. They also indicated that in most soils, calcium may not move down much below 18 inches but magnesium moved down 30 inches or more. It is important when using the flame spectrophotometer to determine the calcium level, that the accuracy of the values be checked chemically using the oxalate-permanganate titration method.

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Florida Pastures Make Good Use of Lime

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The engineering of a successful pasture program involves study and calculations of the soil in all of its many ramifications including moisture availability, temperature conditions, plant species and associations, and management. Lime is only one of the many important phases in such an engineering job; however, it is one of the first considerations and usually requires constant replenishing. Liming of a pasture can be likened to the greasing of a car; when new, a careful, complete grease job is essential and at regular intervals a regrease job is recommended, otherwise the life and usefulness of the vehicle is impaired.

Records for state wide use of ground agricultural limestone applied to pastures or to areas for establishing pastures are not adequate. Florida does, however, use more limestone in her agricultural industry than any other southern state. The National Agricultural Limestone Institute Inc., reports the following tonnage for 1956:

Florida	548,456
Georgia	351,083
Alabama	266,583
Mississippi	354,824
North Carolina	415,990
South Carolina	133,651
Illinois	2,903,674

The tonnage of limestone used on Florida farms in 1956 would allow for a one-ton per acre application on one out of five acres in cultivation or one out of twenty-five acres of all cultivated and pasture land.

Outside of a small area of limestone and marl soils in the state, most soils are acid with pH values of 4.0 to 6.0 Millions of acres under pasture had an original pH of less than 5.0. The flatwoods pasture soils are perhaps the most extensive acid soils in Florida and during the past decade these same flatwoods soils have been shown as some of the most productive of forage and pasture.

The question is often asked, "Why lime?" or "Will liming pastures pay?" In answering this question there are a number of if's, however, it can be said generally that liming pasture soils will pay if soil tests show the soil pH to be strongly acid and if improved pasture species of grasses and or legumes are to be grown—as opposed to natural pasture species.

As cited by Dr. W. G. Blue at this society's meeting in October of 1951 and published in the proceedings Volume XI, liming soils accomplishes essentially three things: (a) changes the soil reaction

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(pH), (b) furnishes a supply of essential plant nutrients calcium and magnesium, and (c) reduces the loss of nutrients by leaching.

(a) and (b), soil reaction and supplying calcium and magnesium, cannot be refuted, and there is sufficient evidence as published by many investigators to prove (c), that a strongly acid soil when limed will retain more of the plant nutrients or in other words retard leaching. It is also true that the so-called minor elements are generally more available in the acid soils, and as soils are limed to near neutrality (pH 7.0) minor element deficiencies or responses are more likely to occur.

During the early 1940's Blaser and Killinger found that white and other clovers could be grown on soils having a pH range of 4.0 to 5.0 after a one-ton surface broadcast application of limestone and treatment with the necessary phosphorus, potassium and minor elements. When this same ton of limestone was disked in or mixed with the soil these same legumes usually failed to produce adequate forage. This, then, became an early recommendation in Florida for the growing of legumes; that is, surface apply one ton of limestone per acre on a prepared seed bed or closely grazed pasture ahead of seeding legumes. For economic reasons, such as poor pasture species, low grade cattle, low price of beef and others, it was difficult to put over a pasture program calling for more than a ton of lime per acre. A brief review of plant nutrition or plant development will quickly reveal the advantages of changing the soil reaction and nutrient supply in more of the soil mass than just the surface. Plant root development, microbial activity—particularly of the *Rhizobium* or nodule forming bacteria and nitrifying organisms, available moisture and many other factors are enhanced when more of the soil mass has been adjusted for plant development by liming. Actually two tons of limestone per acre on most soils more acid than pH 5.0 were necessary when the lime was disked or mixed in the upper three to five inches of the surface soil to successfully grow white clover and other legumes. It was easy to calculate that a two-ton rate of lime nearly doubled the cost of liming. In those early days of pasture pioneering it was often easier to engineer a one-ton surface application of lime every two years than a two-ton application followed by one ton every four years. Either system gave satisfactory results, however the initial two-ton application was somewhat the sounder practice and is quite generally recommended today.

In 1938 Blaser showed that adapted strains of clovers could be successfully grown on our acid flatwoods soils only after the soil or plant lime requirement had been met. About the same time Stokes and Blaser pointed out the need for selective liming of different clovers. Medic and sweet clovers responded to equal applications of calcic limestone more than to dolomitic limestone, whereas white and ladino clovers responded equally to either source of liming material. Gammon has pointed out the need for liming the heavier soils of West Florida. Likewise Hodges demonstrated the need for liming clover pastures in South Florida.

On one experiment initiated about 10 years ago in South Central Florida on an organic soil, white clover failed when either one, two or three tons of lime had been applied along with the necessary phos-

phorus, potassium and minor elements. This same experiment, when revamped with rates increased to six tons of lime per acre, allowed for excellent clover growth.

The chemical composition of the herbage from a limed pasture (acid soil) usually shows an increase in the plant calcium and often the phosphorus and potassium are also increased without the addition of either extra phosphorus or potassium. In an experiment where 72 pounds of N, 144 pounds of P_2O_5 and 100 pounds of K_2O per acre were applied to carpet grass, the addition of one ton of ground calcic limestone increased the plant composition on a dry basis as follows: calcium 0.395 per cent to 0.573; phosphorus 0.161 to 0.234; potassium 0.667 to 0.794; and no change in nitrogen. Calcium and phosphorus are essential for livestock development as well as for plants. Farmers or ranchers sometimes feel that they can "skip" or "get by" without liming or by cutting the amount of lime applied. This attitude makes it doubly necessary to have the proof of returns from a sound liming program.

Sometimes the returns in dollars and cents from liming are realized over a period of years with only small yearly returns. Other times, liming is the key to success or failure and the returns are high the first year as well as succeeding years.

In Florida, ground agricultural limestone of good quality may be purchased with a fineness of grind from very coarse to fine. Florida law does not specify the degree of fineness, however, the producer or seller must tag the limestone giving a guarantee of its purity and fineness of grind. ACP (Agricultural Conservation Program) specifies that approved liming materials are those of sufficient fineness so that at least 50 percent will pass through a 20-mesh sieve and contain at least 90 per cent calcium carbonate equivalent. In this writers opinion, this grade or fineness of limestone would be medium fine, and where minimum quantities were applied at planting or shortly before on acid soils some legume failures would be experienced. Quantities of limestone containing an excess of particles with diameters as large as a dime or nickel or even greater have been spread on Florida pastures. True, these coarser aggregates will last longer by being slower in weathering or dissolving; but the immediate effect is not sufficient for maximum forage production.

As a contrast to lime of which 50 per cent will pass a 20-mesh sieve, a quantity of limestone was recently purchased by the Agricultural Experiment Station from a Florida source having a guarantee of 97 per cent calcium carbonate or equivalent, with 50 percent passing a 60-mesh sieve and 80 per cent passing a 20-mesh sieve. This lime will neutralize the soil acids much more rapidly that the coarser material and would directly contribute to the success of a legume pasture seeding. More attention should be paid to fineness of Florida-produced agricultural limestones.

It can safely be said that the liming of pastures or pasture soils in Florida, particularly those with legume mixtures, has been a key to successful and profitable livestock production.

Marl Soils: A Review

John L. Malcolm*

Marl soils deserve a place in a lime symposium for the contrast they provide. In Dade County we are farming a "soil" very similar to the limestone which is applied to the soil in other parts of the State. The most important lesson which can be learned from this situation is that an excess of calcium carbonate may require some special treatment but need not be looked upon as an impossible barrier to successful crop production.

In 1930, Skinner and Ruprecht** described the Glade soils as consisting of a mucky layer 6 to 12 inches deep underlaid by calcareous material. The muck has disappeared and the marl at the present time is that underlying calcium carbonate layer with the residue of the mucky layer mixed in by repeated cultivation.

This marl contains 90 to 95 percent calcium carbonate. Skinner and Ruprecht reported that a typical sample contained, in addition to the calcium carbonate, 2.11 percent silica, 0.26 percent magnesium, 0.15 percent phosphorus, 0.08 percent iron, and 0.001 percent manganese. The nitrogen content was 0.33 percent, indicating roughly 6 percent organic matter. More recent analyses indicate that these values can still be considered typical. However, many samples contain less silica and the phosphorus content is usually lower in virgin marl, particularly that found southwest of Florida City. The marls studied by Skinner and Ruprecht were mostly from the Franjo and East Glade sections and were subject to periodic flooding with salt water. The low silica content of these soils precludes the possibility of a significant clay fraction.

The pH of Perrine marl soils varies from 7.5 to 8.8. Samples brought directly from the field seldom run above pH 8.0, probably because of the high carbon dioxide content. Prolonged drying will raise the apparent pH.

Mechanically the marl is a silty clay loam. More than 95 percent of the marl sample from the Sub-Tropical Experiment Station Highlands Farm can be washed directly through a 200-mesh sieve. The remainder is composed of root fragments, other organic derbris, and pieces of disintegrating shell.

From the chemical and physical analyses it is apparent that these soils are high grade agricultural limestones. They could not be recommended for use where magnesium deficiency was prevalent.

The Perrine marl is deficient in some elements and requires fertilizer to produce maximum yields. It is known to be deficient in nitrogen, phosphorus and potassium. Among the minor elements manganese is the key to farming the marl. The discovery of the essentiality of manganese by Skinner and Ruprecht changed Dade

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**Skinner, J. J. and Ruprecht, R. W. 1930. Fertilizer Experiments with Truck Crops. Fla. Agr. Exp. Sta. Bul. 218.

County farming from organic gardening to a commercial enterprise. One authentic case of magnesium deficiency has been seen in the Eureka Glade at Lindgren Road.

It is probable that deficiencies of copper, zinc, boron, and iron occur under some conditions but no consistent field response to these elements has ever been obtained.

All of the evidence which we have to date indicates that the calcium supply in this soil is adequate. Although the pH causes many people concern, it appears to be a matter of little consequence to the plants. It is of more interest that with proper seed disinfection potato scab is not a serious problem on these marls in most years. Tests with the use of sulfur have consistently failed to show any advantage. Likewise, at least on potatoes, ammonium sulfate and nitrate of soda were equally effective sources of nitrogen over a period of years.

With an adequate fertilizer program, the yields of vegetables on the marl soils are equal to or better than those obtained in other parts of Florida. Due to the unique seasonal advantage the net returns are usually better than in other areas.

The marl has some very serious disadvantages. Because it is subject to flooding, farming during the summer months is impractical. Even during the normal cropping season, a high water table often limits the effective depth of the soil. This interferes with root development, nitrification and sometimes with tillage and other cultural operations. The fineness of the particles in the marl make it particularly treacherous when it is wet. It frequently is necessary to abandon ground spraying at the most critical time because machinery cannot be used on the wet marl. It was to offset the poor bearing quality of the marl that the high clearance crawler tractor was developed.

A point of interest concerning the marl which comes under neither fertility nor productivity is the reaction of calcium cyanamid. This material which usually retains its phytotoxicity in the soil for weeks or even months, can be applied to the marl at the rate of 1000 pounds per acre the same day that beans or potatoes are planted without inhibiting germination or sprouting.

Considering the success of marl farming, the only just conclusion is that for vegetable crops at least there is no such thing as too much calcium carbonate. The abundance of calcium must be balanced by an adequate supply of the other elements required for plant growth but no exotic chemical compounds or complicated art is required to make these elements available.

SYMPOSIUM: RADIATION GENETICS

Mutation Production By Ionizing Radiation

THOMAS S. OSBORNE*

INTRODUCTION

This discussion is based on two major premises: that high-energy radiations can cause hereditary changes, and that some of these changes are beneficial either to the organism enduring the change, or to the needs of man as served by the organism.

To understand the biological effects of these radiations and how they are put to the breeder's use, we must first understand something about the nature of the radiations themselves. What are they? Where do they come from? What are their properties? How do they affect living tissue, especially the genetic apparatus? How does one go about using them? And, finally, what combinations of rays and techniques are best for inducing mutations in a particular organism?

BASIC PHYSICAL AND BIOLOGICAL CONSIDERATIONS

Genetically Important Radiations

Radiations now considered suitable for use in mutation induction are: X rays, produced by roentgen apparatus; rays from radioactive nuclides, such as alpha, beta, and gamma rays; accelerated (charged) particles, *i.e.* protons and fast electrons; neutrons, fast and slow; and for some purposes, ultra-violet rays. All in this group produce ionization in tissue, either directly or indirectly, except the low-energy ultra-violet rays.

Origins of These Radiations

X rays, heretofore the radiation most commonly used for mutational purposes, are produced when a stream of electrons is drawn *in vacuo* through a potential difference of many thousands of volts, jumping a gap and striking an anti-cathode of some heavy metal such as tungsten. The sudden deceleration of these fast-moving electrons results in a considerable loss of energy, most of it as heat, but a part as X rays. The use of X-ray machines is of course widespread in diagnosis, therapy, and experiment; some such machine is usually available to the determined geneticist. It should be noted that X rays are produced among the orbital electrons of the anti-cathode, that is, *outside* the atomic nuclei.

Alpha, beta, and gamma emissions arise from the nuclei of unstable atoms, either natural or artificial ones. Some of the more common naturally-radioactive elements are radium, potassium-40, and carbon-

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14. Since the advent of the nuclear reactor, which induces radioactivity in virtually any element, there is a great variety of artificially-produced unstable isotopes.

Protons, together with neutrons, make up most of the nucleus of every atom. The simplest source of a proton beam is ionized hydrogen which, having lost its one electron, has a "bare" nucleus consisting only of a proton, and this proton by virtue of its positive charge can be accelerated to high energies by various devices.

Fast electrons. In a similar operation, one can "save" the electrons thus stripped from hydrogen atoms and because of their negative charges accelerate them to high energies, producing a beam.

Neutrons. As mentioned, neutrons and protons make up most of the nucleus of any atom. An early source of neutrons was obtained by permitting alpha particles to strike light atoms such as beryllium or boron or lithium, producing one neutron per reacting atom. Radium is a common source of alpha particles, and small radium-beryllium sources are now in use for measuring moisture in soils by scatter and absorption of the neutrons produced.

Such neutron sources are unimportant to the geneticist in view of the many nuclear reactors now in existence. The reactor depends on the ability of such heavy atoms as uranium-235 to split or fission, yielding on the average more than two neutrons per neutron absorbed. (It may be noted that in the lighter atoms such as are commonly found in plant tissue the ratio of neutrons to protons is about 1:1, but in heavier elements the ratio may be higher than 1.5:1, as in the common isotope of uranium. With an atomic number of 92, hence 92 protons in the nucleus, and an atomic weight of 238, uranium-238 thus has 146 neutrons and a neutron:proton ratio of 1.59:1.)

Ultra-violet rays are of course a part of sunlight, and lie in their energy spectrum between X rays and visible light. For genetic purposes ultra-violet rays may be produced by any of several simple and inexpensive lamps.

Properties of These Radiations

X rays are similar in nature to visible light, and are what physicists call electromagnetic radiation. X rays, however, are of much shorter wave-length, and thus have much higher energy than visible light. If one visualizes the light spectrum from red down through violet and beyond to ultra-violet, X rays lie still further down the scale. The range of wave-lengths usually considered to be important in biological effects of X rays is 10 to 0.1 Angstroms. An Angstrom (abbreviated A) is 10^{-8} cm or 10^{-4} microns or 0.1 millimicron. (For comparison, red light has a wave-length of about 6,000 A.)

The well-known fact that X rays can penetrate several centimeters of tissue and still activate a photographic film is the basis for using X rays in diagnosis. As one might expect, the energy of an X ray is directly proportional to the energy utilized in the machine producing the rays, thus the energy range of such rays is from a few thousand electron volts (kev) to several million electron volts (mev).

Finally, it should be noted that X rays produce their biological effects mainly by ionization, *i.e.*, by ejecting orbital electrons in the tissue being irradiated. The energy required to ionize an atom is about 10 to 15 electron volts (ev), but it happens that about 32 ev are dissipated per ion-pair formed, the difference being energy given up for excitation. Excitation is important in such considerations as dosage intensity and fractionation, about which succeeding speakers will, I am sure, have more to say.

Gamma rays, sometimes called nuclear X rays, are emitted from the nuclei of unstable atoms but are otherwise quite similar to X rays. They are electromagnetic rays of shorter wave-length, thus higher energy than most X rays and are extremely penetrating. Their wavelengths are usually designated as 0.1 A to 0.001 A, the latter corresponding in energy to about 12 mev and capable of penetrating several centimeters of heavy metal. Common sources of gamma rays for biological studies are cobalt-60, emitting two gamma rays of 1.17 and 1.33 mev, and cesium-137, with a single gamma ray of 0.67 mev.

Beta rays, which are negative electrons emitted from nuclei of unstable atoms, are less penetrating than are gamma rays and produce an ion density in tissue between those of alpha and gamma rays. One of the most common and energetic beta emitters is phosphorus-32, with an average energy of 0.4 to 0.5 mev.

Alpha rays (or particles) are also emitted from the nuclei of radioactive atoms and consist of bare helium nuclei, *i.e.*, of two protons and two neutrons. Alpha particles are less penetrating than any of the previously mentioned radiations and in fact can be stopped by a few sheets of paper. This is despite the fact that they may exist in such extremely energetic forms as the 5.1 mev alpha ray of plutonium-239. There is an important relationship here: Owing to its double charge, an alpha particle loses its energy quite rapidly, leaving behind a short but very dense column or cluster of ionizations.

Of these three nuclear emanations, gamma rays are by far the most widely used for inducing genetic changes.

Protons, having a mass of one and a single positive charge, are produced in beam form by electrical and magnetic devices which strip electrons from hydrogen atoms and accelerate the bare protons. When thus accelerated they are capable of reaching extremely high energies and of penetrating very deeply; thus in a synchro-cyclotron, protons can attain energies of 150 mev or more and penetrate nearly eight inches of tissue!

Fast electrons are ordinary electrons accelerated by similar devices (linear accelerators, cyclotrons, synchrotrons, megatrons, bevatrons, *etc.)* to very high energies. Ten-mev electrons can penetrate about 30 millimeters of tissue (of unit density).

Such accelerators are still rather rare and expensive, and the beam at usable distance is quite narrow compared to the exposure areas needed for most genetic studies.

Ultra-violet rays are produced in relatively inexpensive mercury lamps which can be bought in most any drug store. The range of

wave-lengths is usually considered to extend from about 4,000 to 1,000 A. Ultra-violet is but slightly penetrating, thus is used in genetic studies only on such thin and unprotected tissue as pollen grains, but here it is quite effective in producing genetic changes.

Neutrons. The neutron is a normal constituent of every atomic nucleus (except H) and has, like the proton, a mass of one—but no charge. Because of this electrical neutrality it is not deflected by the electric field around an atom but can penetrate to the nucleus, thus the usual course of a fission (or fast) neutron through any substance is a series of collisions with nuclei, which in hydrogenous material results in a number of ejected protons—themselves densely ionizing. The neutron continues its course with head-on and elastic collisions, losing energy at each encounter, until it is slowed to ordinary or thermal energy and at this time it is capable of being captured by a target nucleus which is thus made unstable or radioactive. To become stable again, this "new" nucleus emits some kind of radiation—alpha, beta, or gamma—either immediately or at some later time (as much as several thousand years later), after which it is once more stable.

The boundary between fast and slow neutrons is an arbitrary one. Henshaw *et al.* (27) stated: "A fast neutron may arbitrarily be described as a neutron more likely to produce an ionization track by elastic scattering than by being captured, that is, with energies from 10^3 ev to more than 4 mev. By the same reasoning, a slow neutron may be described as one more likely to produce an ionization track by being captured than by elastic scattering, with energies less than 10^3 ev." However, Curtis *et al.* (11) considered the fast neutron component of a mixed spectrum to be "that part having an energy greater than 0.1 mev" (10^5 ev).

(It may be of interest that a free neutron is itself radioactive, with a half-life of about 20 minutes, decaying to form a proton and an electron.)

More thorough discussions of radiation physics may be found in Glasstone (20), Gray (22), Kirby-Smith (30), and Oster and Pollister (40).

Effects of Radiation on Living Tissue

In deference to the speakers to follow, I shall consider this topic only in general terms.

Since ionization is the removal of orbital electrons and since these electrons produce the binding forces of molecules, ionization or removal of these electrons causes disruption of the integrity of a system. The biological effects, then, of a particular radiation depend in large part on the density of these columns or clusters of ionization, since knocking one electron from a chromosome and another electron from another chromosome must be less drastic than producing a cluster of several hundred ionizations in a single chromosome thread. In this regard, the very slow and doubly charged alpha particle can produce many thousand ion-pairs per micron of tissue traversed, whereas the extremely fast and uncharged gamma rays of cobalt-60 produce less than 10. Soft X rays lie somewhere in between.

X rays and gamma rays interact with matter by three primary methods: the photoelectric effect, Compton scattering, and pair production. Because the proportion of each process depends on many factors (including the voltage of an X-ray machine) and because the effects of the three processes are different, one must be cautious in comparing the biological effects of, say, 10,000 roentgens (r) from an X-ray machine operating at 50 kv with another operating at 250 kv, and these with the 1.2 mev gamma rays of cobalt-60.

Beta rays are associated with rather intermediate energies and ionization densities, seldom penetrating more than a few hundred microns of tissue. Thus for genetic purposes, a beta-emitting isotope must either be absorbed into or near the chromosome (1, 14, 19, 58) or it must be put in an evacuated system for use on such thin tissue as pollen grains or microorganisms (31).

The short range of alpha rays accentuates the need for proximity, but their very high ion density makes them quite effective if released near the genetic target (58).

Beams of protons and fast electrons are little used for mutational purposes, and the protons of most interest to us are those produced in tissue by interaction of incoming neutrons with nitrogen and hydrogen.

Fast neutrons do most of their damage by sending protons through tissue as the result of head-on collisions with hydrogen nuclei. Such neutrons, usually from fission, have energies up to 15 mev and produce extremely dense columns of ionization. Slowed to thermal energy, the neutron has insufficient force (only a fraction of one ev) to continue this process and is easily captured by any nucleus. This would seem to be the end of the matter, but the mere addition of this slow neutron to the nucleus raises its energy by several mev. The nucleus is, in other words, made radioactive. To become stable it must give up this excess energy, which it does in the form of alpha, beta or gamma rays.

Ultra-violet rays appear to yield more intragenic changes and less gross chromosomal aberrations, when delivered to pollen grains or tubes, than do the ionizing radiations (28). Comparisons of efficiency of these kinds of radiations *per erg absorbed* are of questionable accuracy, due to the proportion of ultra-violet absorbed before reaching the cell nucleus; this is difficult to estimate, but undoubtedly high for most organisms.

Units of Measurement

To the average plant breeder, the most confusing feature of literature on radiation-biology may well be the multiplicity of measurement units necessarily (?) employed. Thus he reads of roentgens, reps, rems, rads, dps, dis, ergs, curies, rutherfords—and many more. A few of these units are important to his understanding of the subject.

The roentgen or r is best remembered by the biologist as that amount of X or gamma radiation which produces, in one cubic centimeter of dry air at standard conditions, one electrostatic unit of electricity. While this is a very small amount of electricity, and the rise in temperature which its absorption would cause is immeasurably

tiny, 1 *r* is nonetheless equivalent to more than 2 billion ionizations!

For various reasons, the *r* is an unsatisfactory unit for comparing effects of different radiations on different systems, so the *roentgen equivalent physical* (*rep*) was devised. This is the amount of any kind of radiation resulting in the dissipation of 93 ergs per gram of water or wet tissue.

The roentgen equivalent man (*rem*) was devised for considering the biological effects on humans of an amount of any radiation equivalent to 1 r of X or gamma rays. The value of the rem thus varies with the kind of radiation and with the particular biological effect studied.

The rad is a unit based on the rep, and is an absorbed dose yielding 100 ergs per gram of absorber. There is some feeling that the rad may supplant the rep in biological studies (30).

Measurement of the quantity of a radioactive substance (*e.g.*, phosphorus-32) is usually given as the disintegrations per second (*dps*) which a certain amount of the substance is emitting. Thus *one curie* (*abbreviated c*) is a quantity of any isotope decaying at the rate of 3.7×10^{10} dps. The customary amounts used on plants are millicuries (10^{-3} c) and microcuries (10^{-6} c). A similar but simpler unit is the *rutherford*, corresponding to 10^{6} dps; it has not come into widespread use.

For most plant breeding work, the precise measurement of radiation dosage is impracticable. For example, a given amount of gamma radiation will compute to different numbers of roentgens depending on whether it is delivered to a thin or thick sample, to "dry" seeds or "wet" buds, even depending on the chemical composition of the sample. The usual compromise is to read intensity at the sample position with a gas-filled chamber of the "Victoreen" type, calibrated in r-units, and to state the treatment as air-dose.

Likewise, the *rep* of a particular neutron irradiation will depend on the frequency of neutrons of various energy-ranges, the probability of capture ("cross-section") of neutrons of each energy by each element in the biological sample (thus requiring complete qualitative and quantitative analysis of the sample), the kind of emission resulting from each capture or collision, and the proportion of each emission expected to be absorbed inside the tissue being considered. Thus a compromise is generally used, which is to state the intensity (flux) of neutrons of a given energy-range reaching a square centimeter of sample every second (n cm^{-2} sec^{-1}). The difficulties incident to obtaining complete spectral dosimetry in a neutron facility are hinted at by Curtis *et al.* (11).

USING RADIATIONS IN PLANT BREEDING

The breeder intent on using radiations intelligently should first become acquainted with general works on biological effects of radiation. Certainly the primer is Lea (34), and the volumes edited by Hollaender (28) contain a wealth of information. The reader should by all means digest the excellent summary of twenty-five years' work in Sweden on radiation genetics and breeding (58). Also pertinent

are Genetics in Plant Breeding, 1956; Shapiro, (48); Radiation in Plant Breeding, 1957; Proceedings of the Geneva Conference, 1955; and Radioactive Isotopes in Agriculture, 1956. One of the most thorough review papers dealing explicitly with this field is that of Harold H. Smith, to be published soon in The Botanical Review.[1]

Choice of Methods

Goals of the breeder. The methods one uses depend in large part on his purposes, which may be to study critically the statistical variability from irradiation, as has Gregory (18, 24, 42). He may want to induce certain definite mutations (17, 32), to translocate blocks of genes from "wild" to stable chromosomes (16,47), or simply to hasten flowering in bulbs (45). His goal may be to obtain "perpetual hybrids" of the Oenothera type by inducing large associations of chromosomes. It may be to increase crossing-over between tightly linked loci, or to produce monosomics for genetic study of polyploids. Perhaps any alteration is of potential value, as in ornamental plants.

Nature of the plant. Besides his explicit goals, the breeder must consider certain limiting features inherent in the plant he is endeavoring to change. Is it self- or cross-pollinated? Is it of use mainly for vegetative or for seed production? Has it been improved mainly through hybridization or "sports"? How easily would chimeras be recovered? How much time does a generation require? Is it annual or perennial? . . . and so on.

Stage of life cycle for irradiating. For annual seed-producing plants, seed irradiation offers several advantages: large numbers may be treated at one time; large populations may be grown; the tissue can be brought to reproducible conditions; severe alterations of irradiation environment (gases, temperatures, moisture, chemicals) may be used; and the size and state of the material permit it in many cases to be fitted into devices where larger parts would not fit, and to be sent long distances when certain radiation sources are not locally available. One finds in the radiation-breeding literature that the dormant seed is by far the tissue most frequently irradiated.

Similar arguments may be made for irradiating dormant buds in plants where seed production is not certain or where heredity is unstable. The chief disadvantage to bud and seed irradiation is that a desired change may be wrought in only one or a few cells, which produce such a small sector of the mature plant as to be unperceivable, or the altered cells may be so injured as to be "outgrown" by normal neighboring cells and never manifested.

Irradiation of actively-growing somatic tissue appears to offer all the disadvantages of seed or bud irradiation, with the dubious advantage of being more sensitive to radiation thus requiring a smaller dose for a given effect.*

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[1]Manuscript generously furnished in advance of publication.

*However, it is possible to irradiate active shoots of periclinal chimeras and destroy only the outer layers of the stem apex, permitting expression of genetically different inner layers, as Sagawa and Mehlquist (Amer. J. Bot. *44*: 397-403, 1957) have so elegantly shown in the carnation.

If one irradiates just before or during meiosis, he can expect a high frequency of gross aberrations and greatly reduced fertility; this is generally considered a poor time to induce maximum mutations (13, 44, 49). One might argue, however, that the death of cells carrying gross rearrangements during the two meiotic and two microspore divisions should be an effective screening agent if one desires mainly "intragenic" changes.

Conger (47) has pointed out some of the advantages inherent in pollen irradiation. Briefly, these are: a change induced in a single cell will (if it fertilizes an egg) be represented in every cell of the progeny; an inviable change produces no progeny, requiring no testing; and simple sources such as ultra-violet or soft X rays may be used effectively. Conger also points out that pollen which is trinucleate at the time of irradiation should perpetuate more changes than pollen which is binucleate and must undergo another haploid division.

Pollen irradiation would seem a likely method for producing "structural heterozygotes" which often manifest heterosis. This would seem most practical on long-lived species such as forest trees, where the F_1 would occupy the land for a considerable period and transmission to progeny is relatively unimportant as a consequence.

The one-celled zygote affords another opportunity to obtain a uniform (non-chimeric) individual, but the difficulty of finding large numbers is usually insurmountable.

Techniques of Irradiating

External irradiation. The extremes of exposure to radiation are often described as "acute" for short, intense treatments and "chronic" for longer exposures at lower intensity. Generally, dormant tissue is given acute irradiation while active cells may be treated in acute, semi-acute, or chronic fashion.

One of the most famous systems for chronic irradiation is the "gamma field" at Brookhaven National Laboratory, designed both for basic (55) and applied (48) research. Plants are grown in concentric circles around a kilocurie cobalt-60 source, being irradiated almost constantly, with the intensity determined by the radius of the circle. After exposures of a year or more, plants are removed to a normal environment and observed for mutations. Preliminary reports[2] indicate important mutants, such as earliness, lateness, and firmness of fruit in the peach, are being recovered by this method.

Several ingenious devices for irradiating small laboratory samples of all kinds have been devised. For those who prefer (and can afford) lead shielding, there are indoor systems (12, 23), and a "portable" 1-ton, 200-curie field machine (33). Indoor earth- and water-shielded machines have been designed (4, 46).

The UT-AEC laboratory in 1956 built a rather inexpensive 100-curie cobalt-60 gamma-ray source, shielded by earth and water. Similar to (but much smaller than) the one being built here at Gainesville,

[2]Seymour Shapiro, personal communication.

it was largely designed by Homer Patrick[3] and has been used for acute and semi-acute irradiation of dormant and hydrated seeds, dormant scions and budwood, young trees, roots, rhizomes, meiotic plants, cats, rats, mice and hamsters.

We also have access to the unique, multi-source gamma-field designed primarily for animal experiments by Wilding *et al.* (59), which provides a low, uniform flux over several hundred square feet. Plants in pots or tubs are moved in for the desired period, then removed.

For the person interested in irradiating parts of single cells, an unusual micro-beam of protons has been described (62).

Absorption of radioisotopes. When plants are permitted to take in radioactive forms of elements which are normal constituents of the chromosomes (*e.g.*, P-32), genetic changes may be caused both by the columns of ionization produced when rays are emitted and also by valence changes from nuclear transformations. Thus cytogenetic changes were found after Tradescantia buds were permitted to absorb P-32 (19). Uptake of P-32 by seeds of wheat and barley was found (2) to yield many "mutants," none of which bred true. P-32 and S-35 were found less effective than soft X rays administered to dormant seeds, as measured by translocations in microsporocytes (39).

Comparative efficiencies of different radiations. Arnason and Morrison (1) found the relative efficiencies of certain radiations in producing chromatid breaks in Tradescantia buds to be:

0.14 and 0.20-mev X rays:	100
1.25-mev gamma rays from cobale-60:	78
23-mev particles from a betatron :	71

These data fit well with those of Kirby-Smith and Daniel (31).

Fast neutrons have been found (15) to be 10 to 40 times as effective as X or gamma rays in producing growth retardation, sterility, and mutations. Thermal neutrons gave higher frequencies of survival per chromosome interchange than did X rays, administered to dormant barley seeds (7).

One can infer from data given that fast neutrons are about 35 times as effective as thermal neutrons physically (8), and 20 to 50 times as effective biologically (6). However, Ehrenberg and Saeland (15) computed that thermal neutrons were more efficient than fast neutrons per energy unit dissipated.

Caldecott (6) concluded that relatively sparsely ionizing radiations such as X rays and 2-mev electrons affect both genetic and non-genetic systems in seeds, whereas the more densely ionizing neutron reactions principally affect the genetic apparatus. A similar conclusion was reached by Ehrenberg *et al.* (14).

Conger and Giles (10) made a comprehensive analysis of the sources of ionization in Tradescantia buds exposed to thermal neutrons. They found that 99 per cent of the ionization resulted from capture in the tissue of neutrons by only three elements: hydrogen, nitrogen, and boron. Boron alone was responsible for 30 per cent of

[3]Unpublished.

the ionization absorbed, although it existed as only 2.9 ppm of the wet weight of the tissue! (Boron has a cross-section for capture of thermal neutrons some 400 times that of most other biological elements.) Conger (9) followed this finding to its logical test by adding boron to the plant medium, then irradiating with thermal neutrons; chromosomal damage was increased.

Factors modifying radiosensitivity. Before discussing doses found empirically to be effective, we should consider some factors of known importance in the rather wide differences in response to radiation often observed.

We at UT-AEC have found, as has Gustafsson (25) that seeds of many Cruciferae are 2 to 10 times more resistant to radiation than are seeds of most Gramineae. A variety may be twice as resistant as a sister-selection, and polyploids sometimes tolerate 2 to 4 times as much radiation as related diploids. For want of knowledge, we explain such differences as being "genetic."

Permitting seeds to imbibe water normally increases their radiosensitivity 5 to 10 times; however, Caldecott (5) found increasing sensitivity as seeds were dried below their normal range.

Sparrow and Forro (54) in their review pointed out that protection against radiation damage is conferred by such conditions as reduced oxygen tension, added indole acetic acid, glutathione (and various SH-compounds), strong reducing compounds, succinate and formate, and reduced water content. Some or all of these factors reduced injury to such varied tissues as spores of Aspergillus, pollen of petunia, and seeds of barley.

An increase of radiosensitivity from increased oxygen tension is almost universal. The much-described "oxygen effect" is thoroughly discussed in the review paper of Nilan (38).

Nilan (37) altered the cytogenetic effects of X rays by altering the gas and or temperature around barley seeds during irradiation. From his results, one could apparently keep a high mutation rate but reduce aberrations by irradiating in carbon dioxide at dry-ice temperature.

The rather controversial increase of cytogenetic damage often found when infra-red is superimposed on ionizing treatments has received a new interpretation from the careful work of Withrow and Moh (60).

Steffenson (57) has shown that chromosomes may be broken, and radiation effects accentuated, when tissues are deficient in calcium, sulfate, or magnesium.

The important changes in chromosome sensitivity during division, with metaphase 50 times more sensitive than interphase, were shown by Sparrow (52).

Gustafsson and Nybom (26) found that treating seeds with colchicine prior to X-raying, while not altering the frequency of mutants, did increase materially the proportion of rare mutants.

An inhibition of callus and root formation was reported by Einset and Pratt (61) after grape cuttings were irradiated. This hypersensitivity of root primordia is an argument for using budwood and scions in plants of this type.

In some cases, Sparrow (53) found sensitivity to chronic irradiation directly correlated with chromosome size.

Doses found effective. Abnormalities of many plant genera grown under chronic gamma irradiation have been reported by Sparrow, see Nilan, (38). Minimum daily dose producing "severe" effects ranged from 30 r/day for Lilium to 6,000 r/day for Gladiolus.

A similar range for response of dormant seeds to X rays was shown by Gustafsson (see Nilan, (38)), with 90,000 r having no more effect on mustard or rutabaga than did 7,500 r on hemp or peas.

"Suitable" doses for dormant seeds of the three ploidy groups of oats (25) are:

2x	4x	6x
5,000 r	5-10,000 r	15,000 r

Some "standard" doses used by the Swedes are shown in Table 1.

TABLE 1.—Some Doses of X Radiation Routinely Used by Swedish Workers for Mutational Purposes.
(Compiled from Torssell, 58.)

Organism	Condition of seeds	Dose, Thousands of r	Results	Reference page
Barley	Dry	5.	17% X_1 survival 1.3% chlorophyll mutants X_2	545
		7.5	13% X_1 survival 0.6% chlorophyll mutants X_2	
		10.	5% X_1 survival 0.4% chlorophyll mutants X_2	
Oats, Wheat } 6x	Dry	10. and 20.	More mutants are recovered in 6x than in 2x cereals; "the polyploid can better bear a chromosomal alteration"	549 ff.
Lupinus luteus	Dry	12.5 to 17.5	26% X_1 survival; 6.2% X_2 mutants	569
Vicia sativa	Presoaked 24 hours	15.	2.2% X_1 survival Many "degenerates" in X_2	565
Parvus sp.	Presoaked 24 hours	15.	2.4% X_1 survival; "optimal dose" (!)	558

In our cooperative irradiation program at UT-AEC, we have treated seeds of 50 field and garden plants with gamma rays of cobalt-60. Reports to date show that for about 90 per cent of these species, a survival curve from little killing to almost complete killing results from a range of 10,000 to 50,000 r. With our source of "mixed" neutrons, a wider range is necessary for a similarly inclusive curve: from about 0.5 to 5.0 hours.

Concerning tissues other than seeds, Granhall (21) irradiated scions of certain fruit trees and found the dose of X rays killing 50 per cent of the population (LD-50) was about 5,000 to 7,500 r for apples and pears, and about 2,500 to 4,000 r for plums and cherries.

Bishop (3) used 3,500 to 4,000 r of X rays on dormant scions of four diploid apple varieties, based on previous dosage studies. The second year after grafting, fruit were produced and many showed changes in size, shape, and color.

After considerable experience irradiating maize pollen, Stadler and Roman (56) considered 400 r of X rays to be a "low" dose and 1,000 r to be their "regular" dose. Dollinger (13) gave 2,000 r of X rays to maize pollen without complete killing. When Tradescantia buds received 500 r of X rays after meiosis, less than 10 per cent pollen abortion resulted (44).

At UT-AEC in 1956, we irradiated mature cotton pollen for one of our cooperators[4] with 400, 800, 1,600, and 3,200 r of gamma rays. The few seeds produced at 3,200 r failed to germinate in 1957, while the 1,600-r treatment yielded many viable seeds with great apparent variability in the offspring. This appears to be a very promising technique.

Concerning dosage of ultra-violet, Tradescantia pollen-tube chromosomes will tolerate as much as 4×10^3 ergs mm^2, and maize pollen, 1.32×10^5 ergs/mm^2 (28).

The difficulties besetting dosimetry and comparison of different neutron facilities have been mentioned earlier. Morris (35) exposed maize tassels to thermal neutrons for 0, 1, 2, 4 and 8 minutes. At the lowest dose, 22 per cent, and at the highest dose, 91 per cent of the F_1 progeny had "abnormal" pollen. Flux was 4.2×10^{12} neutrons cm^2/min., which was calculated for this material to be 94.41 rep min. Presumably, calculations were done in the manner of Snyder (51).

From data of Caldecott *et al.* (7), one can compute that an "average" LD-50 for barley seeds was achieved by an exposure to a total of 10.2×10^{12} thermal neutrons cm^2; the comparable figure for X rays was 11,200 r.

Testing for Mutants

It is generally considered that virtually all induced mutations behave as recessive genes, thus are not manifested in the treated generation (variously called X_1, N_1, R_1, *etc.*) However, apparently dominant mutations have been found following irradiation (32) and one can easily rationalize that a heterozygous locus could be made homozygous-recessive by ionization, thus yielding a visible mutation in X_1 that is nonetheless recessive.

[4]Unpublished data, U. S. Cotton Field Station, Knoxville, Tenn.

Most screening for mutants, however, is done in the generation following irradiation, called X_2, N_2, *etc.* This presupposes selfing or close inbreeding in X_1, making recessive mutants homozygous. It cannot be too strongly emphasized that a past history of self-pollination in a crop is of absolutely no value in insuring self-pollination of the X_1. A radiation treatment which causes obvious injury will almost invariably cause some male-sterility also, rendering the plant receptive to normal pollen carried by insects and wind. It seems likely that many cases of so-called radiation induced mutants can be explained by such outcrossing. If we are to assess the real value of radiation in plant breeding, we must remove this possibility beyond any doubt. This means isolating the X_1 in figurative capital letters, underscored, with added exclamation points. Admittedly this is difficult or perhaps sometimes impossible, but there is no other way to be certain whether a new type is the result of an altered gene or of an adulterous pollen grain. I challenge anyone who insists his crop will never outcross to surround his X_1 with a variety having a dominant marker.

Another factor which may mislead us is apparent stimulation of treated populations, which may be due to inadequate size of controls. Admittedly, the stimulation that many of us find at low doses may be real, but only reasonable numbers of untreated controls will verify this matter. In this regard, I would like to commend the very careful studies of Dr. Wallace of your University, who is using equal numbers and equally rigorous selection in treated and control populations.

The apparent frequency of induced mutations will depend largely on the ease with which one can screen for them. Such "easy" tests as those for disease resistance, winterhardiness, and straw stiffness are usually indicated as the most likely justification for radiation-breeding. With characters more difficult to perceive, the use of progeny-rows is urged to minimize the needle-in-haystack effect which in my experience is an appalling situation to face. If the "easy" test is considered foolproof, one may justifiably bulk his X_1 harvest and X_2 planting, weighing the savings in labor and bookkeeping against the possibility of an inadequate test, which would leave him with an immense X_3.

In testing, the breeder is concerned with populations, probabilities, and individuals or units. Conger (42) has emphasized this concept, pointing out that in irradiation of cereal seeds, for example, the culm is the unit, since there may be as many genetically different progenies as there are X_1 culms. Similarly, when pollen is treated, the unit is the pollen grain, each of which may give rise to a genetically different individual. Further, Conger points out, "if a potato is irradiated, there can be as many genetically different individuals as there are eyes or buds that survive; it is the number of buds, not number of spuds, that counts."

It follows that one should test as many progenies as possible, taking (as a rather extreme example) 3 seeds from each of 1,000 X_1 plants rather than 1,000 seeds from each of 3 plants. It is suggested[5] that for crops like small-grained cereals, one may test virtually all the X_2 if the X_1 is so thickly planted as to yield few culms per plant and few seeds per culm. There is, however, a possibility that this technique

[5]K. J. Frey, personal communication.

would handicap altered primordia, and it should be studied further.

Gustafsson (25) found 1 progeny in 10 from irradiated seeds to carry recognizable recessive mutations; about 1 in 800 of these mutants was considered desirable. Thus if the breeder plans to test one progeny per plant, these figures would suggest that his X_1 number at least 8,000 viable seeds.

Gustafsson also urged that where yield of seed is important, X_1 plants of good fertility should be selected. Lowered fertility is often associated with gross chromosomal aberrations which will lower fertility of the progeny.

With such tissue as budsticks, the bud is the unit to be tested. An original method for exposing all the buds on one stick simultaneously to a range of radiation doses is suggested by Karl Sax.[6] A budstick is placed parallel to the beam of rays, apex toward the source, so that delivered dose may vary from perhaps 30,000 r at the apex to 5,000 r at the cut end (due to the inverse-square law). Killing decreases with distance from the tip, and by noting position and growth of each bud, one obtains a dose-response curve from a single stick.

It would seem reasonable to increase the frequency of mutant recovery in the same way as in inducing polyploidy; *i.e.*, by removal of apparently unaltered plants or branches to encourage growth of damaged plants or tissues.

The current philosophy is to use massive doses to reduce the likelihood of unaffected cells. This philosophy may prove to be completely erroneous, since it necessarily entails inducing gross aberrations with their concomitant diminution of yield. MacKey says on this point (58): "When testing more deviating mutations for yield the results have always been discouraging." The Swedes are in one experiment re-irradiating annually in an effort to accumulate small, quantitative changes.

The fact that apparent mutation rate is non-linear—*i.e.*, falls off at high doses—has been explained by Muller *et al.* (36) to mean that at more severe doses, cells in which mutants were induced do not survive to be represented in the progeny. On this point, Jordan *et al.* (29) reasoned that if a particular mutation frequency is low, a low survival rate may be insufficient for revealing any mutants.

For the breeder intent on causing small, intragenic changes without accompanying aberrations, the data of Caldecott (6), equating mutations with aberrations, seem discouraging. It should be remembered, though, that these data concern *populations* whereas the breeder is interested in individuals, one of which may well depart significantly from this curve.

As our techniques improve, we may eventually be able to deliver small doses of radiation and select for propagation only those cells with mutations. Such, at least, is our hope.

Conclusions

The use of radiations in plant breeding is very promising, but far from simple. The optimum methods to be used in a particular case vary with many factors—biological, chemical, physical and economic.

[6]Personal communication.

The key to successful radiation-breeding is not in producing mutations, but in *finding* them. It is useless to induce a mutation in a cell that subsequently dies. It is useless to induce a mutation in a cell that will not divide, or that will not divide a sufficient number of times to make recognizable new tissue or parts. It is useless to induce a mutation in vegetative tissue of an annual plant unless (by grafting or rooting) one can cause proliferation of altered tissue as germinal tissue. It is useless to induce a mutation in a cell that received such change as to be unable to compete with neighboring cells.

It is, in other words, useless to induce a mutation which one cannot *find* for any of these reasons, or because its frequency is too low, or because the testing methods are too insensitive.

Obviously, what one needs is a high proportion of changed individuals, each individual genetically uniform, in a small population that is under very discriminating pressure. One's thoughts inevitably turn to irradiation of pollen.

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The Effects Of Radiation On Genes

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The problem of the effects of radiation on genes consists of two parts: first, what is a gene?, and second, what are the effects of radiation on genes?

WHAT IS A GENE?

Definition and Properties

The gene is operationally defined as a unit of heredity. For a purely formal theory of gene behavior, such as Mendel proposed, nothing need be assumed about the physical nature of the gene except that some genes exist in alternate forms or alleles. However, we know from genetic and cytological evidence that genes are arranged in linear order on strands that correspond exactly to the microscopically visible chromosomes and are contained within the nuclei of cells. Many forms of life, including fungi, bacteria, and viruses, show evidence of heriditary units that are to varying extents analogous to the genes of higher forms.

From the persistence of genes from generation to generation we infer that the gene must be capable of inducing the formation of exact copies of itself, that is, be capable of autocatalysis. Furthermore, because we study genes by virtue of the effects they produce, such as flower color, plant size, etc., the gene must be able to catalyze other reactions, that is, must have heterocatalytic properties. Thus, the gene's function can be considered that of transmitting genetic information that assures both its own reproduction and its hetrocatalytic function.

In addition to genes determining exact copies of themselves for generation after generation, there occasionally arise changed forms of genes called mutants, that are able to reproduce the new form exactly in each subsequent generation.

The gene is a unit of heredity in the classical sense, a unit of function in phenotype production, and also a mutational unit. The term "gene" has been recently subjected to considerable scrutiny, and it may be replaced by other, more specific, terms such as the "recon", "muton" and "cistron" proposed by Benzer (2).

Relationship of Nucleic Acid to Genetic Material

The genes that behave in regular ways in breeding, that are autocatalytic and heterocatalytic and mutable are remarkable indeed. What do we know about the stuff from which they are constructed? The following five lines of evidence point to nucleic acids as the building blocks for genes.

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(1) *Nucleic acid content of chromosomes and nuclei*—Cell nuclei and chromosomes, the microscopic structures that include the hereditary units, contain nucleic acid.

(2) *Similarity of the nucleic acid ultraviolet absorption spectrum and mutation action spectrum*—Nucleic acids absorb certain narrow bands of ultraviolet light and readily transmit others. Because the wave lengths of ultraviolet light most effectively absorbed by nucleic acid were very similar to those most effective in inducing mutation, Hollaender and Emmons (10) concluded that the genes must be made of nucleic acid or some material intimately associated with nucleic acid, such as protein.

(3) *The role of nucleic acid in bacteriophage reproduction*—Bacteriophages are bacterial viruses. They contain nucleic acid surrounded by a protein sheath. They attack bacteria and inject their nucleic acid into them where the bacteriophage may mate and multiply. A number of hereditary characters are known from bacteriophages. In order to assess the genetic roles of nucleic acid and protein, Hershey (9) carried out experiments in which bacteriophage nucleic acid was labeled with radioactive phosphorus and radioactive sulfur. His tracer experiments showed that upon penetration of the bacteria all of the bacteriophage nucleic acid, but only 3% of the bacteriophage, protein entered the cells. He concluded from this that the nucleic acid is the portion important to the virus reproduction, although a genetic role for the 3% of protein could not be excluded.

(4) *The role of nucleic acid in tobacco mosaic virus reproduction*—Isolated tobacco mosaic virus (TMV) particles consist of cores of nucleic acid surrounded by sheaths of protein. Different strains of TMV exist that can be distinguished by means of the disease symptoms they produce or by chemical analysis. Recently Fraenkel-Conrat *et al.* (6) separated the protein and nucleic acid portions of TMV. They found that the nucleic acid, but not the protein portion was still infective. Thus, the core of nucleic acid contained the portion of the virus that was essential to reproduction.

If virus was reconstituted from separated protein and nucleic acid fractions the characteristics of the reconstituted virus were those of the strain from which the nucleic acid rods had been derived and were not dependent upon the characteristics of the protein donor. These relations are shown in *Figure* 1. Thus it is clear that in TMV some sort of hereditary information can be transmitted by nucleic acid alone.

(5) *The role of nucleic acid in bacterial transformation*—Still further evidence linking nucleic acid and hereditary material is obtained from studies of genetic transformation in bacteria. It has been found that cell-free extracts of one strain of the pneumococcus bacteria can convert members of another strain to the first type. The transformed types continue to reproduce the new form and their extracts can in turn be used to transform other bacteria (11). Fractionation and purification of the pneucococcus transforming extracts has shown that the active substance is nucleic acid.

Nucleic acid	Protein	Phenotype (disease symptoms)
TMV	—	TMV
HR	—	HR
—	TMV	none
—	HR	none
TMV	TMV	TMV
HR	HR	HR
TMV	HR	TMV
HR	TMV	HR

Figure 1.—Phenotypes (disease symptoms) produced by protein and nucleic acid alone and by reconstituted virus.

Although it is not intended to completely equate the genetic systems of higher forms with those operative in bacteria and viruses, we can conclude from these lines of evidence that nucleic acid is either closely related to the hereditary material or is indeed the hereditary material. Implications of the latter possibility will be further explored in the following sections.

Chemical and Physical Structure of Nucleic Acid

The nucleic acids extracted from cell nuclei are long polymers that exhibit flow birefringence and viscosity. Chemical analysis has shown that nucleic acid from most sources is made up of nucleotide units that each consist of a purine or pyrimidine base attached to a sugar, which in turn is held by an ester linkage to inorganic phosphate. In

most organisms from which nucleic acid has been isolated, the nucleotides of the two purine bases, adenine and guanine, and the two pyrimidine bases, cytosine and thymine, occur in almost equimolar amounts (3). In the nuclear and chromosomal nucleic acid of most organisms the sugar is deoxyribose and the bases are adenine, guanine, cytosine and thymine. This type is called deoxyribose nucleic acid or DNA. In the DNA of some organisms cysosine is found to be partially replaced by 5-methyl or 5-hydromethyl groups and the sugar to be partially replaced by glucose (5). In the nucleic acid of some viruses, such as TMV, the sugar is ribose and the bases are adenine, guanine, cytosine and uracil. This type of nucleic acid is called ribose nucleic acid or RNA.

Critical evidence for the physical structure of nucleic acid has come from X-ray diffraction pattern analysis. To make such a test, a collimated beam of X-rays is aimed at a nucleic acid preparation and the diffraction pattern studied for evidence of regular molecular structure. Watson and Crick (20) found that the X-ray pattern from isolated nucleic acid was consistent with an intertwined double helix, each strand of which was approximately the width of the length of a nucleotide unit. That the structure is not an artifact is indicated by further X-ray studies that have revealed a similar structure for DNA from sperm heads and bacteriophage (21). Titration of nucleic acid indicates extensive hydrogen bonding (4). Watson and Crick (19) have postulated that DNA is made up of double helical nucleotide strands held together by hydrogen bonding between the purine and pyrimidine bases, and that, from structural considerations, the purine and pyrimidine bases are paired. This base pairing scheme is shown in *Figure 2*.

Size of the Gene

Benzer (2) has attacked the problem of what is the relation between genetic length and molecular length in work with the T-4 strain of bacteriophage. This strain behaves as a haploid with one linkage group, i.e. as though it has only one chromosome. By assuming that

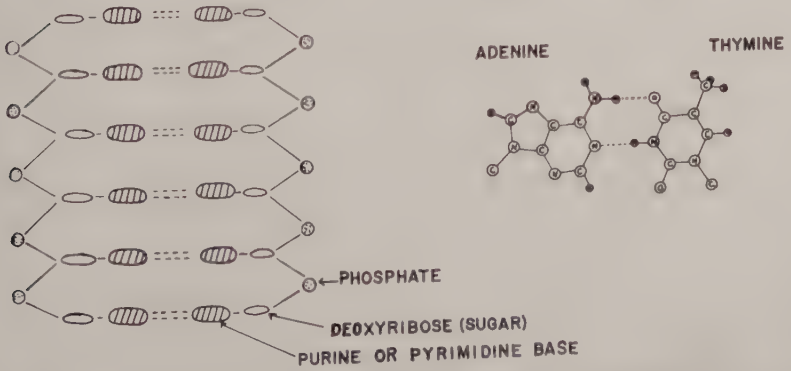

Figure 2.—Backbone structure and base pairing scheme for DNA according to Watson and Crick (19).

the Watson-Crick double helix is the form of the genetic material, that only one copy of the genetic information exists per bacteriophage particle, and that 40% of the DNA is genetic. Benzer has calculated that the single bacteriophage linkage group or "chromosome" is about 80,000 nucleotide pairs long. It can be estimated very roughly that what may correspond to a gene is on the order of one hundred nucleotide pairs (2). In *Drosophila* the size of a gene has been estimated from target size calculations to be in the range of 1000 to 10,000 atoms (13), which would make up about 15 to 150 nucleotide pairs.

Reproduction of Chromosomes and Genes

What do we know about the method of reproduction of genetic material? From direct evidence we must turn to studies with chromosomes, the gene carriers. Mazia and Plaut (12) used the radioactive carbon labeled DNA precursor thymidine on root tips of *Crepis*, a plant with a small number of exceptionally large identifiable chromosomes. After a period of time the root tips were fixed, stained, and radioautograms prepared. It was found that the cells which received labeled thymidine at early interphase of cell division had at the following anaphase six chromosomes which contained radioactivity (presumably new) and six chromosomes that were relatively non-radioactive (presumably old). However, Taylor *et al.* (18), who used tritium labeled thymidine concluded that each chromosome consisted partly of an old strand and partly of a new one.

Can we account for how this formation of new genetic material exactly like the old takes place? Watson and Crick (20) have postulated that the reproduction of genetic material takes place on the face of the double helix structure by a template system. They envisage that this happens through separation of the twin helix strands followed by the formation of new hydrogen bonds with complementary free nucleotides from within the cell. The nucleotides held in place by hydrogen bonding then link up through sugar phosphate bonds to form a new double helix identical with the parent one. The evidence from chromosome reduplication may require that another step occur in which the original helix is reformed as a unit.

We see that in a general way the Watson-Crick model of nucleic acid structure provides a plausible basis for the structure and template reduplication of genetic material.

How Could Genetic Information be Carried and Function?

If we assume what is plausible, namely that nucleic acid is indeed the genetic material, that a Watson-Crick model explains its structure and reduplication, and that a gene may consist of possibly 100 nucleotide pairs, how can we explain the transmission of the kind of information that genes must carry in order to bring about their observed effects? The only idea that has been advanced by which the relatively monotonous Watson-Crick nucleotide helix could transmit the necessarily complicated hereditary information is that information is somehow coded into the nucleic acid by the order of nucleotide pairs. In

the simplest case the genetic nucleic acid contains the nucleotides of adenine, guanine, cytosine and thymine. As paired nucleotide bases in a double helix, in which a purine base nucleotide is paired with a pyrimidine base nucleotide, four possible base pairs can exist: A — T, G — C, and the two reversal types, T — A, and C — G. It can be seen that if only the order of base pairs were involved in the code, the number of combinations possible is 4^n, where n is the number of nucleotide pairs in a gene. It is apparent that such an assumption would permit the existence of a very extensive array of genes.

A simplified picture of how coded information on a Watson-Crick gene might give rise to a phenotype is illustrated in *Figure 3*. For the purpose of the illustration it has been assumed that this gene consists of 10 nucleotide pairs, that it functions through determining the specificity of a particular enzyme, that its specificity might be transferred through RNA, and that the gene specificity is determined by the order of its four possible nucleotide base pairs. The RNA and enzyme specificity are here indicated by surface outlines. It is conceivable that the somewhat different shape of the enzyme surface would permit partial activity; however, a more extreme modification of the gene, so that it produced a very different enzyme, would be expected to be an inactive allele.

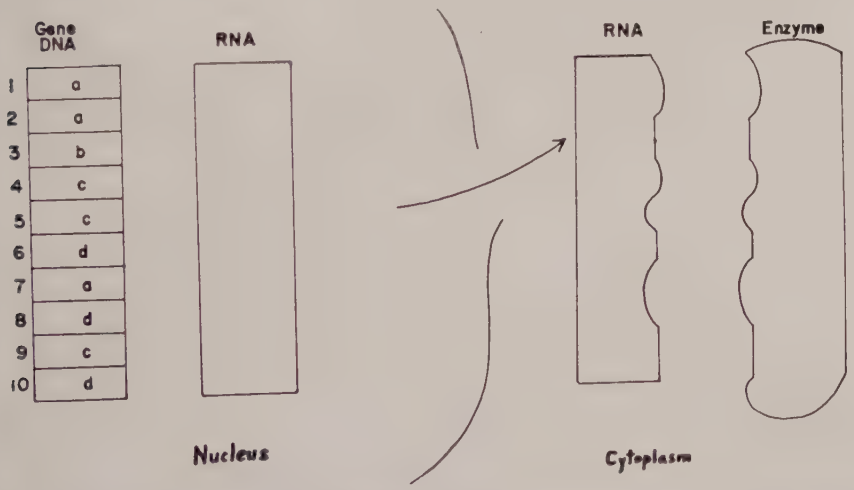

Figure 3.—How coding of information in a nuclear gene DNA might impart surface specificity to RNA, which in turn might transfer specificity to an enzyme. The four kinds of base pairs are indicated by a, b, c, and d.

THE EFFECTS OF RADIATION ON GENES

A discussion of the effects of radiation on genes must be preceded by a discussion of what radiation is and what it does to matter. Fortunately Dr. Osborne (15) has very capably discussed the forms of radiation, so we can go on to the effects of radiation on matter.

Effects of Radiation on Matter

Ultraviolet light—Ultraviolet light has sufficient energy to excite molecules but not sufficient energy to produce ionizations. An excitation raises the energy of a molecule and as a consequence, increases the probability that the molecule will undergo chemical reaction.

Ionizing radiation—Ionizing radiations are able to produce excitations, eject electrons and break chemical bonds. The amount of energy that can be dissipated in tissues by ionizing radiations is so great that reactions occur which have almost zero probability of occurring spontaneously. Many effects of ionizing radiations on matter are destructive ones; for instance, gamma irradiation of nucleic acid solution was found to produce free purine bases, ammonia, and inorganic phosphate (1).

Effects of Radiation on Genes

Inasmuch as we do not know exactly what a gene is, the title: "The Effects of Radiation on Genes" should be rephased to: "What radiation might do, or seems to do to genes."

Changes in genes or their expression that might be expected as a consequence of radiation are:

(1) The loss or change of a gene associated with a demonstrable loss or rearrangement of chromosomal material. Here it is pertinent to recall that both ultraviolet and ionizing radiations can cause chromosome breaks and deficiencies (17).

(2) The apparent but not true gene mutations. Included in this group are changes of the same type as (1) that are too small to detect but are nevertheless at an intergenic or supragenic level.

(3) The true intragenic mutations which could include: loss of part of a gene, inversion or rearrangement of parts within a gene, or addition of material to a gene.

The determining factor in one's interpretation of whether intergenic or intragenic mutations are involved in any particular case may depend on one's optical equipment and techniques.

There are two opposing views on whether radiation can produce the true gene mutations. Muller (14), who has worked with *Drosophila*, believes that radiation can induce gene mutations. He reports that in addition to mutations which are associated with rearrangements, position effects, etc., there are many carefully analyzed cases where apparent gene mutations carry no detectable chromosomal aberration, and in which suppressor genes have been excluded. In his favor it must be admitted that *Drosophila* salivary gland chromosomes offer the best cytological material known for detecting minute structural chromosome changes. In further support of his contentions, Muller argues that the induction of intermediate alleles and reverse mutations with radiation can best be interpreted on the basis of radiation induced true intragenic mutations.

On the other hand, Stadler (16) questioned the existence of radiation induced intragenic mutations. He worked with corn and found that apparent gene mutations induced by ionizing radiations frequently consisted of deletion, chromosomal rearrangements, and position effects, and were usually of extreme phenotype compared to the intermediate alleles obtained from spontaneous mutation or to some extent those from ultraviolet light. He has pointed out the ambiguous position of his argument by admitting that "A mutant may meet every test of a gene mutation and yet, if it is not capable of reverse mutation there is ground for the suspicion that it may be due to gene loss, while if it is capable of reverse mutation there is ground for the suspicion that it may be due to an expression effect." The expression effects to which Stadler referred are cases where the gene itself is not altered, but changes elsewhere alter its expression. He pleaded for an answer to the problem by careful study of mutation and reverse mutation at single genetic loci.

Stadler's arguments are for the most part still unanswered. However, let us examine some of the evidence on mutation of individual genetic loci in the ascomycete fungus *Neurospora*. *Neurospora* is especially suitable for reverse mutation studies because of the readiness with which one can work with large numbers of individuals. *Neurospora* has normal though small chromosomes and is especially favorable for genetics because the four meiotic products can be recovered. In *Neurospora* many radiation-induced and spontaneous mutants of the "lost function" type have been recovered that grow only if the medium is supplemented with the appropriate organic substance that the mutant is unable to synthesize. Spores of a deficient mutant, for example, one requiring the amino acid methionine, spread on a petri dish containing agar and the minimal medium do not grow unless methionine is added. If, however, among the spores of the methionine requiring mutant there are any in which a reverse mutation to methionine independence has occurred, such spores will grow to form colonies. Screening of this sort permits examining large numbers of irradiated cells for reverse mutations. Giles (7, 8) has reported on reverse and forward mutation in *Neurospora* mutants requiring methionine, inositol, adenine, and tryptophan. His extensive tests did not establish that radiation can induce true intragenic mutations, but they showed the following interesting points:

(1) The case of apparent reversal of the methionine requiring mutant were all due to suppressor genes.

(2) Different examples of what appeared to be mutants at the same inositol locus could be distinguished on the basis of different reverse mutation rates with radiation. One inositol mutant was almost non-reversible with ultraviolet light but responded readily to X-rays.

(3) Crosses of a series of X-ray induced allelic mutants for adenine requirement showed that many were associated with changes that affected crossing over in adjacent portions of the chromosome, and therefore probably carried chromosomal aberrations.

(4) Among 23 X-ray induced adenine requiring mutants, only 7

underwent reversion spontaneously or by X-ray treatment, whereas one spontaneous and five ultraviolet induced adenine requiring mutants at the same locus all reverted.

(5) Radiation was found to induce allelic mutations for partial and absolute tryptophan requirement. Revertants obtained from the tryptophan requiring mutants included intermediate and completely reverted or wild types. Application of fluorescence analysis and a series of chemical tests to the various absolute requirement and intermediate type mutants revealed that several classes could be distinguished. The situation is represented in *Figure 4*. Giles suggested that his mutants might all be different.

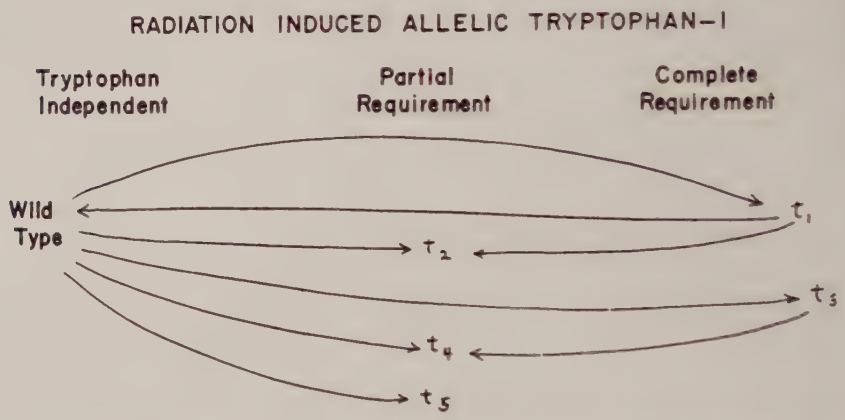

Figure 4.—Types of radiation induced changes in phenotype at the tryptophan-1 locus in *Neurospora*. From Giles (8).

Giles' data provide important evidence on forward and reverse mutation at what appear to be specific genetic loci. He found that some reversions were traceable to modifying genes. However, the failure to find modifiers responsible for the reversions at other genetic loci suggest that modifying genes are not responsible for the adenine, tryptophan and inositol revisions. The reversibility of some mutations induced by radiation and the production of intermediate alleles both from partial forward mutations and partial reversions argues strongly for intragenic changes being involved. The lower incidence of reversible mutants among those produced with ionizing radiation (X-rays) compared to ultraviolet light or spontaneously fits well with the accepted notions that ionizing radiation causes more serious effects than does ultraviolet light. The simplest explanation of Giles' findings, in which radiation is able to cause both mutation and subsequent reversion, is that true intragenic effects have been induced. However, alternate explanations involving closely linked suppressor of modifying genes cannot be excluded.

We thus have a model of the genetic material that explains some of the physical and chemical data about nucleic acid and the reduplication of genetic material. We know from model chemical systems

that radiations can break chemical bonds which could disrupt the genetic material; however, until there is information about the details of reduplication and failure of reduplication at a molecular level, there can be little advance in our knowledge of how radiation affects genes.

SUMMARY AND CONCLUSIONS

Radiation is able to induce changes that are called mutations and are often assumed to be intragenic mutations in the true sense. Critical evaluation of the evidence indicates that the existence of radiation induced true intragenic gene mutations cannot be rigorously proven. The recent structural model of the genetic material proposed by Watson and Crick provides a very plausible basis for gene structure. It is hoped that further study of the gene by chemists and physicists will be as fruitful as their attack on the atom.

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The Effects Of Radiation On Chromosomes

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Chromosomes may be affected by radiation in a variety of ways: i.e. the clumping of metaphase chromosomes and irregular separation of chromatids at anaphase may occur (53), mitiotic chromosomes may revert to earlier stages (4). Ionizing radiation may alter the chromosome number to haploidy (68) to aneuploidy (18) or to polyploidy (38). In addition to these and other changes within the cell, ionizing radiations and U.V. produce the initial step in the formation of chromosome aberrations; that is breaks in chromosomes and chromatids. The broken ends may reunite (restitute) in which case no aberrations will be observed. Data from Tradescantia indicate that about 90% of the initial breaks restitute (37). If the broken ends unite with those of other chromatids or chromosomes or fail to restitute, then aberrations may be detected.

No new basic types of aberrations are produced by radiation. The same types of aberrations have been detected in unirradiated material as occur in irradiated material, but at much lower frequencies (Giles, 19, 21). Only a small fraction of spontaneous aberrations can be accounted for in terms of natural radiations. The radiation dose received by the plants examined by Giles was about 1800 times too low to account for the frequencies of aberrations (63). Chromosome rearrangements have played an important role in the formation of some races and species (11) and (55). What percentage of the rearrangements, involving in speciation and race formation, were induced by natural radiation is of course unknown, however it may be assumed that the percentage is minute. Frequencies of chromosome and chromatid rearrangements are increased by radiation. Kaufmann (31) reported complex rearrangements in a *Drosophila melanogaster* spermatozoan involving at least 32 breaks after X-irradiation.

Ionizing radiations induce all the known types of aberrations. Early work with U.V. indicated that only chromatid deletions were produced by U.V. (48, 59), however more recent data indicate that U.V. readily induces the same complex aberrations as do x-rays (16, 34).

The frequencies of radiation-induced chromosomal aberrations in different species varies widely. Breaks in about 1 percent of chromosomes in grasshopper neuroblast cells are induced with 24r of X-rays, 400r is required for 1 percent breakage in Drosophila spermatozoa while doses of X-rays from 3,000 to 20,000r have produced no aberrations in the protozoan Holomastigotiodes (32). Within Tradescantia the order of sensitivity to X-rays from low to high is: generative nuclei, roottip cells, microspores, microsporocytes, with meiotic cells 20-50 times more sensitive than generative nuclei (53).

Higher frequencies of breaks involved in aberrations have been found in proximal regions of Tradescantia chromosomes than in

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distal regions in microspores (47, 52). While the original distribution of breaks cannot be directly determined in any organism there is no reason to assume that the initial effects of radiation are non-random. It is assumed that the distribution of breaks involved in aberrations is non-random. It is not known what factors are responsible for the non-randomness of breaks involved in aberrations, however it has been suggested by Sax (47) that stresses initiated by chromosome coiling may throw broken ends so far out of line that restitution in their original positions would be inhibited. That the centromere is involved in aberration production has been shown (44, 49) in the results of irradiating chromosomes containing centromeres and chromosome fragments lacking centromeres. Aberrations were 10 times more frequent in the centrics than in the acentrics. That restitution is a non-random process is indicated by the fact that aberrations are more frequent in regions near the centromere and more frequent in centric than in acentric chromosomes.

Chromosome breakage has been interpreted to result from several ionizations rather than single ionizations on the following bases: Giles (20) compared equal doses of X-rays and neutrons and found that neutrons were much more efficient than X-rays in producing aberrations. Ionizations along a proton track (produced by neutron radiation) are more densely spaced than along an electron track (produced by X-rays), (13). Therefore, when a chromosome is traversed by a proton many ionizations would be produced within it; if only one ionization produced breakage, neutrons should be less efficient than X-rays, because the additional ionizations in the chromosome would be wasted (22).

MODIFYING FACTORS

The age of seed at time of radiation influences the frequency of aberrations. It has been found (41) that with increasing age, 2 to 17 years, wheat seed contain increasing aberration frequencies following X-irradiation. A comparable influence of age of seed on aberration frequency has been reported in barley (28). It has been suggested that chemicals produced in the ageing seed increase the sensitivity of chromosomes to radiation (41).

Influencing chromosome motion by mechanical stresses affects the frequency of restitution and aberrations: centrifugation during X-irradiation (50) greatly increased the frequency of chromatid and chromosome aberrations, indicating that broken ends of chromosomes are separated by centrifugation thereby inhibiting restitution and promoting illegitimate union. Centrifugation 15 minutes prior to X-irradiation (73) decreased aberration frequency. This effect was attributed to compression of the chromosomes and hindrance of motion thus promoting restitution of the broken ends. Application of sonic vibration during X-irradiation (8) increases aberration production. This increase is attributed to the movement of chromosomes being influenced by sonic vibrations which decreased the chances of restitution. Colchicine which inhibits spindle formation and probably also chromosome movement reduces the frequency of radiation-induced aberrations (2).

Combinations of radiations also modify the frequencies of aberrations but interpretation of these modifications cannot be based on any relatively simple assumptions similar to those involving chromosome movement. Pretreatment of Tradescantia pollen tube chromosomes with U.V. before X-irradiation reduced the yield of all aberrations. Post treatment with U.V. reduced the yield of chromatid deletions and exchanges but did not affect the frequencies of other types of aberrations (61). Swanson suggested that the reduction of aberrations in the U.V. pretreatment may result from a greater resistance to X-ray breakage imparted to the chromosome matrix by U.V. Infra-red radiation applied as much as 96 hours before or 15 hours after X-irradiation increases the chromosome aberration frequency (62). The increase in frequency by pre-treatment is taken to indicate that the infra-red effect is caused by an activation of bonds, holding the chromosomes together, so that they are more sensitive to breakage by X-rays. The increase in frequency by post-treatment is interpreted as being caused by a delay in restitution.

Tradescantia microspores treated with X-rays at low temperatures contain higher frequencies of chromosome aberrations than those irradiated at higher temperatures (7, 51). The temperature effect on chromosome aberrations was attributed to more rapid restitution at high temperatures. This temperature effect is completely reversed in the absence of oxygen—more aberrations occur at high than at low temperatures (25) under conditions of anoxia.

The water content of seeds during X-irradiation markedly influences aberration frequency; the frequency is greater when water content of seeds is increased (29). Fast neutron irradiation is not affected by moisture content of material in respect to production of aberrations (35).

It has been demonstrated that the radiation sensitivity of cells is related to the number of chromosome sets they contain. The loss of portions or whole chromosomes is not as deleterious in polyploids as it is in diploids probably because of the buffering action of homeologous chromosomes (58). Higher frequencies of chromosome aberrations have been observed with increasing polyploidy in cereals (57).

Chromosomes can be broken by ionizing and U.V. radiations before they reduplicate in the resting stage with the result that after reduplication two chromatids with breaks at identical loci may be detected. If one of the chromatids of a split chromosome is broken by irradiation, after early prophase to metaphase, different types of deletions or rearrangements may result. Ostergren and Wakonig (42) hold that only chromatid breaks are possible and that the half or sub-chromatid breaks reported by others are not breaks but distortions of chromosome matrices. Radiation induced constrictions or lesions in chromatids at anaphase have been interpreted as half-chromatid breaks in Tradescantia mitosis (40, 60), and in mitotic chromosome of the grasshopper (4). Walters (66) has observed half-chromatid breaks occurring spontaneously at meiosis in Bromus. These interpretations infer that the anaphase chromosome is already split into two threads in anticipation of the next cell division. Slyzinski (56) has shown that X-ray treatment of Drosophila embryos induces aberrations affecting only a few of the chromatids of the chromosomes that ultimately form

the salivary gland chromosomes. In some cases the aberrations involved less than 1/16 of the diameter of the chromosome.

Duryee (12) in X-radiation treatment of amphibian (*Rana catesbiana*) oocytes reported no radiation damage to chromosomes in isolated nuclei while X-radiation of intact cells or micro-injection of cytoplasm from irradiated cells into non-irradiated cells produced chromosome fragmentation. Although these techniques have been objected to (32) as being too drastic, Duryee has presented a strong case for an indirect effect of radiation on chromosomes through the cytoplasm.

Thoday and Read (64) have shown in *Vicia faba* roottips that aberration frequency induced by X-irradiation in the absence of oxygen was reduced to about one-third that observed when radiation was applied in air. The same investigators have shown (65) a much reduced oxygen effect when alpha-particles were used for radiation. Aberration frequencies obtained with neutrons in Tradescantia microspores show an intermediate oxygen effect between the frequencies found for X-rays and alpha-particles (26). Giles and Riley (24) found that oxygen tension is influential only during irradiation. The ion density of the radiation appears to determine the extent of the oxygen effect with the oxygen effect being greater the less dense the ionization.

Before the discovery of the oxygen effect it was generally assumed that the effect of ionizing radiation on chromosomes was a direct one resulting from the ionizing of bonding electrons of the molecules composing the chromosomes by the passage of ionizing particles (6, 36). Radiation produces chromosome breaks in direct proportion to the dose administered (46). Most of the breaks restitute (37); the others may stay open as one-hit aberrations or rejoin with still other broken ends to form two-hit aberrations. Such aberrations are formed only if two breaks are open at the same time and are close together. If irradiation is applied at low intensity some of the breaks will restitute before others are produced. This results in fewer two-hit aberrations occurring than if the same dose were applied at higher intensity (47). Intensity studies of this type in Tradescantia led to the proposal (7) that two types of breaks are produced by radiation: one type which rejoins relatively rapidly and another type which rejoins slowly. Intensity experiments on *Vica faba* seed indicated that X-ray induced chromosome breaks stay open for about two hours (69). Breaks produced in BAL (2-3 dimercaptopropanol) an antioxidant, remained open only one-half hour, (70) thus indicating that reducing cellular oxygen speeds up the restitution process. Wolff and Luippold (71) have postulated that since this type of break stays open for long periods of time and since respiration and ATP are necessary for its rejoining, it is a break of a strong, possibly covalent, bond. Wolff and Luippold (72) using high intensity X-radiation in time intervals up to three minutes found another type of break that either restituted or formed two-hit aberrations very rapidly. The authors postulate that the rapidly rejoining breaks were breaks of ionic bonds. This proposal gained some confirmation in the results of applying the chelating agent Versene and low intensity irradiation. Versene gave a two-fold increase in the aberration yield and it was assumed that the

"ionic" breaks were held open by Versene and became involved in aberrations.

Oxygen may affect the final yield of aberrations in one or more of the following ways (23): (a) by determining the frequency of breaks, (b) by altering cell metabolism resulting in an effect on radiosensitivity of the chromosomes, and (c) by favoring recombination over restitution. These possibilities are not necessarily mutually exclusive and they may all find common ground in the action of H_2O_2 on chromosome breakage. It is generally held that the radio-decomposition of water, with the formation of H_2O_2 in the chromosome or its immediate vicinity, is responsible for a portion of the breakage of chromosomes by ionizing radiations, this usually is referred to as the indirect effect of radiation. The other portion of breakage probably results from direct ionization of the bonds holding the chromosome together, this direct effect is uninfluenced by oxygen tension. Water, exposed to ionizing radiation, is ionized into OH and H radicals, and the interaction of these radicals with each other and with dissolved gases, leads to the formation of HO_2 or H_2O_2, both being very reactive with most organic molecules. Their formation is directly related to oxygen tension when x or gamma radiation is used, but largely independent of oxygen tension when the densely ionizing neutrons and alpha rays are used. The fact that oxygen tension is important only during the time of radiation exposure also fits into the hypothesis that oxygen is part of a reactive system determining the rate of breakage (63).

At present there seems to be little hope of controling aberrations produced by direct ionization of bonds which hold molecules of the chromosomes together. The frequencies of aberrations resulting from the indirect effects of irradiation may be partially controlled by varying temperatures and oxygen tension irradiation or by pretreatment with U.V., colchicine, or by decreasing water content.

ABERRATIONS AND MUTATION

Chromosome aberrations in Drosophila which show no loss of chromosomal material in salivary-gland preparations are mostly inviable when homozygous. This suggests that the production of aberrations has altered the genetic constitution of the chromosomes (32). Demerec (9) tested a series of 26 X-ray induced lethals associated with chromosome aberrations and found that in 24 the locus of the lethal coincided with one of the breakage points. This findings suggests that either a point mutation occurred adjacent to the break or that a gene's function had been modified by displacing it (position effect). Evidence in favor of point mutation has been obtained in Drosophila by studies of dose-frequency relations between lethal mutations and aberrations (30), and by analysis of the modifying effect of near infrared radiation on frequency of X-ray produced lethals and aberrations (33). Spermatozoa of *D. melanogaster* pretreated with near-infrared before X-ray treatment, showed an increase in aberration frequency when compared to controls that received only X-rays, however there was no increase in frequency of sex-linked recessive lethals, although about one-third of them were associated with gross aberrations. An in-

crease in frequency of lethals would be expected if the lethals were dependent on rearrangements for their expression. This evidence indicates that the lethals associated with induced aberrations in *Drosophila* do not represent a special class of position effect (32). Muller (39) has objected to this interpretation and suggests that the near infrared pretreatment may actually increase the frequency of position effect lethals associated with gross aberrations but that the increase is counter balanced by a decrease in frequency of lethals associated with small rearrangements. This involves an assumption, for which there is no experimental support, that small aberrations are not increased in frequency by near-infrared pretreatment.

ABERRATIONS AND CROSSING OVER

Crossing over in Drosophila females is a regularly occurring phenomenon. In Drosophila males crossing over occurs spontaneously at a very low frequency but it can be increased by X-radiation as shown by Patterson and Suche (43). Crossover frequencies in females may also be increased by radiation (68). Induced and natural crossing over have many similarities; exchange takes place at identical loci when chromosomes are four-stranded, and the recombination classes are usually not lethal. Shapiro (cited in Kaufman, 32) found a higher frequency of crossing over at 3000 than at 1500r, but only a slight increase was obtained at 4500r. He concluded that crossing over may be the result of chromosome breakage by ionization, but that selective elimination of germ cells may account for the declining proportion of detectable recombinations with increasing dosage. It is not known whether processes leading to natural crossing over are similar to those leading to radiation induced crossing over.

CHROMOSOME BREAKAGE WITH CHEMICALS

A very large number of chemicals are known to induce chromosome aberrations. These chemicals are not of any particular type, and their action in breaking chromosomes is assumed to be as variable as their structure. The variation in action is not at present thought to be related to structural or chemical reactivity but probably to penetration. Von Rosen (45) proposes that the radiomimetic effects of chemicals in the cell are a result of enzyme poisoning.

Ionizing radiations are assumed to induce breaks at random in the chromosomes. A non-random distribution of aberrations, induced by different chemicals, has been found in several organisms. These findings have been interpreted as indicating that there are portions of chromosomes that are preferentially attacked by chemicals. Non-randomness of aberration distribution produced by chemicals is most marked when the concentration of the chemical is low, the non-randomness tends to disappear when an excess of the chemical is applied (17). Graf (27) in comparing X-ray induced aberrations with aberrations induced by maleic hydrazide found that chemically induced aberrations were highly correlated with knob number in corn, while X-ray induced aberrations were independent of knob number.

This is interpreted as supporting the hypothesis of Ford (17) that some chemicals cause breakage selectively in the heterochromatic regions of chromosomes.

In general, chemicals that induce aberrations also induce mutations. X-rays induce many more aberrations than do mustard, diepoxide and triazine compounds when sex-linked lethal frequencies are used as a basis of comparison, (1). There is evidence although indirect that some chemicals may be efficient in inducing mutations while inducing few or no gross chromosomal aberrations. Demerec and Hanson (10) found very slight lethal effects of $MnCl_2$ on *E. coli* while it proved to be efficient in producing non lethal mutations. The absence of a lethal effect was assumed to result from the absence of gross chromosome aberrations. The absence of a lethal effect was not associated with concentration of the chemical.

Ehrenberg et al (14) found that solutions of Nebularine induced chlorophyll mutations in barley while the percentage of sterile spikelets in the treated material was lower than that of the control plants. These results are interpreted on the basis that chromosome rearrangements leading to sterility were not induced by the chemical. Cytological examinations were not conducted, therefore this interpretation has not been directly confirmed.

USES OF ABERRATIONS

Chromosome aberrations have been used to assign genes to linkage groups, to demonstrate that genetic crossing over is accompanied by chromatid crossing over and to maintain certain gene combinations by reduction of crossing over. Burnham (3) has outlined a method for obtaining complete homozygotes in corn with the aid of translocations. He assumes the existence of a multiple-translocation stock such that its F_1 produced by crosses with normal corn would have a ring of twenty chromosomes at meiosis. This F_1 plant would produce two kinds of functional gametes which would correspond to those of the parents. The selfed F_2 progeny from this F_1 should contain heterozygotes with the chromosome ring, and two kinds of normals each homozygous for one of the two parental gametic combinations. The application of this method still awaits the production of the multiple translocation stock; a certain number of radiation induced translocations have been built up to give small rings in corn.

Aberrations have been used to transfer and maintain certain desirable genes from one genome to another. Sears (54) transferred leaf rust resistance from *Aegilops umbellulata* to bread wheat by adding the chromosome carrying the gene controlling resistance to the wheat genome. This chromosome was frequently lost in pollen and carried genes which reduced yield. It did not pair with any wheat chromosome so transfer by crossing over was impossible. The gene for rust resistance was eventually transferred to a wheat chromosome by means of an X-ray induced intercalary translocation which did not carry the deleterious Aegilops genes.

Elliot (15) succeeded in transferring stem rust resistance from tall wheat grass (*Agropyron elongatum*) to wheat by the use of X-ray induced translocations. The transfer was accomplished in segregates of

the cross octoploid wheat-Agropyron ($2n = 36$) x hexaploid spring wheat ($2n = 42$). The hybrid seeds of this cross ($2n = 49$) were treated with X-rays and an X_2 wheat-like plant carrying rust resistance was found. Cytological examination indicated that translocations between Agropyron and wheat chromosomes had occurred and that intact Agropyron chromosomes and portions of Agropyron chromosomes carrying genes for grass-like characters had been eliminated. A chromosome number of $2n = 42$ was found in the wheat type plants which carried rust resistance.

It should be emphasized that induced aberration techniques are used in plant breeding as adjuncts to classical methods and in order to attain an understanding of the results obtained, a large backlog of cytological and cytogenetic data is necessary.

SUMMARY

Both ionizing and U.V. radiations induce breaks in chromosomes, which lead to a great increase in aberration production over that occurring spontaneously.

Initial breaks occur at random, however illegitimate union and restitution are non-random. Breaks involving sub-units of chromatids have been observed and combinations of radiations indicate that potential breaks can be induced.

Chromosomes may be broken directly by ionization of bonding electrons of the molecules composing the chromosomes by ionizing particles, or indirectly by the action of radicals produced by ionization of water outside the chromosome. The frequency of breaks produced by the indirect effects of radiation may be partially controlled by various methods.

Chromosomes may be broken by a wide variety of chemicals whose breaking action seems to be selective for certain portions of chromosomes in contrast to the random breaking action of radiations.

Gross chromosome aberrations induced by radiations are usually deleterious to the organism in which they occur and at present there are no methods for their elimination. There is evidence that certain chemicals (Nebularine, $MnCl_2$) may produce a high rate of mutation without producing gross chromosome aberrations.

Radiation induced aberrations have been successfully used in plant breeding to aid in the transfer of desirable genes from one genome to another. At present these techniques seem to have limited applicability.

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The Utilization Of Artificially Induced Mutations In Plant Breeding Programs

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A plant breeder might ask, "Should I make artificial induction of mutations a part of my program?" There is no short answer to this question because it depends on a number of variables, including species of plant, existing natural genetic variation, and available screening techniques. This means of creating new genetic variation is a valuable tool, but it is obviously not equally well suited to all plant breeding problems.

In this paper I shall give a few examples of beneficial (to man) mutations that have been induced by radiation; and I shall discuss the main difficulties involved in isolating the desired mutants, the barriers to immediate practical use of many such mutants, and the situations in which artificial induction of mutations seems most likely to be fruitful. The paper is primarily a brief review of literature and no originality of ideas is claimed.

EXAMPLES OF BENEFICIAL MUTANTS

Highly desirable mutants have been isolated from a variety of crops following irradiation of seeds. The following serve as illustrations of what has been accomplished:

(1) A mutant resistant to five races of the fungus causing powdery mildew of barley was induced by X-radiation in Austria by Hansel and Zakovsky (1). The strain was otherwise of normal appearance and yielded significantly more than the parent variety in years when the disease was a serious problem.

(2) High resistance to certain races of crown rust and stem rust in oats has been found (2, 3).

(3) Earliness in lupines (*Lupinus luteus*) was induced by X-radiation (4), and alkaloid-free variants of lupines were found in irradiated populations by Sengbusch and Hackbarth, as reported by Gustafsson and Tedin (5).

(4) A bush-type navy bean mutant was produced in the Michelite variety by Down (6). This growth habit was previously unknown in the navy bean type. Its main advantage is that the upright growth allows free air circulation, eliminating Sclerotinia rot, which is serious in the vine-type navy bean. Also, combine harvesting of the bush type may be practicable.

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(5) Increased resistance to Cercospora leaf spot and stem rot of peanuts was found by Gregory (7). He also isolated five mutant peanut lines which were on the average significantly higher yielding than five similarly selected control lines.

(6) Self-compatability in *Prunus avium* was induced in a previously self-incompatable strain (8). This results in better fruit set and allows continuous selfing if desired.

(7) The transfer of leaf rust resistance to common wheat from a distant relative, *Aegilops umbellulata*, was made possible by use of X-rays (9). This involved the translocation of a small segment of an Aegilops chromosome to a wheat chromosome.

(8) Shorter, stiffer-strawed types which resist lodging have been found in barley (10) and oats (2).

These mutant strains are very definitely beneficial to man and represent striking plant breeding advances. The particular genes involved were not readily available in cultivated stocks. Possibly some of the same mutations have occurred in nature and will occur again; however, artificially inducing these mutations was no doubt the most effective way of obtaining the desired results.

While mutation breeding has been successful in the above instances and in many other experiments not mentioned, there are important limitations to practical application of the technique. These limitations may be classed in two groups: (1) the difficulties involved in isolating or finding the desired mutants in the first place, and (2) barriers to immediate release of the mutant strains as commercial varieties once found.

DIFFICULTIES IN FINDING BENEFICIAL MUTANTS

Mutations are easily induced by several types of radiation, and also by a number of chemical compounds. The mutation rates following irradiation of seed or pollen vary widely depending on length of exposure and numerous other factors, but they are usually several thousand times higher than spontaneous mutation rates (11).

For every mutation that might be called beneficial, there are unfortunately several hundred deleterious mutations produced by radiation (12, 13). Rigid selection is necessary to sort out the few desirable mutants and discard the rest. Large numbers of second generation irradiated progenies must be grown, and efficient screening techniques are almost essential if there is to be reasonable hope of success.

The beneficial mutants listed previously were obtained only by a large amount of work. For example, Freisleben (14) tested 240,000 seedlings from 12,000 X_1 plants of barley to find just one line which was immune to three races of the fungus causing powdery mildew. Another example is the work of Gregory (15) with peanuts, in which about 75,000 seeds were irradiated and detailed observations were made on 132,000 X_3 plants. These illustrations serve to emphasize the importance of working with large numbers in this type of breeding.

Efficient screening for the desired mutation can rather easily be done in searching for resistance to such diseases as crown rust of oats,

powdery mildew of barley, etc. Resistance to a given race of the disease-causing fungus is usually controlled by one gene, and resistance vs. susceptibility is rather clear cut. Also, small grains are well suited to mass screening techniques because large numbers of seedlings can be grown in a small space where environmental conditions favoring disease spread can be maintained. An example of an extremely large scale screening procedure was reported by Wheeler and Luke (16), with which they were able to test approximately 45,000,000 oat seedlings for resistance to Helminthosporium blight.

When effective screening is not possible the job becomes difficult because much more testing must be done. For characters which are controlled by many genes and are readily influenced by the environment, such as vigor or yield, at least hundreds of progenies need to be tested in replicated plots at several locations for a period of years. This scale of testing could easily overburden the facilities available, to the detriment of the remainder of a conventional plant breeding program. In other words, the use of radiation seems poorly suited to improving quantitative characters such as yield, as far as identifying the desired mutant is concerned.

POSSIBLE BARRIERS TO EARLY RELEASE OF MUTANT STRAINS

It would be nice if you could irradiate seed of a variety which had an undesirable character, select a mutant in which the undesirable character was corrected, and release the new strain as a commercial variety as soon as seed supplies could be built up. Occasionally it may be possible to do it that simply, but the chances are greater that more breeding work will need to be done before the new mutant can be of benefit to farmers.

There are two main reasons why new mutant strains probably will not be ready for farm use. One is that ionizing radiations such as X-rays and gamma rays cause a great many chromosome aberrations or breaks, which result in deletion, inversion, and translocation of chromosome parts. Because of these aberrations, radiation-derived strains, especially of oats, are often not stable genetically. Some irradiated strains of oats "defy cleaning up" (13). This problem of genetic instability is found primarily in the polyploid cereals, but chromosome deficiencies if at all large would seriously unbalance the genotype of any plant. In such cases the new mutation would not show its positive value until placed in a new genetic environment by a series of backcrosses.

The second reason that new mutant strains probably will not be ready for early release is that the great perponderance of mutations are deleterious to the plant. It is logical to assume that if a beneficial mutation has occurred in a cell which contains hundreds (perhaps thousands) of genes, the probability is good that one or more other genes have mutated to an undesirable state. If these deleterious mutations are fixed along with the desirable one the latter will not be able to express its full effect. Here again the desired gene must be transferred to a genotype which will allow its most favorable expression.

The problem under discussion can be well illustrated by the example of the bush-type navy bean which was listed earlier as a beneficial mutant (6). The history of this strain goes back to 1938 when seeds of the Michelite variety were X-rayed at Michigan State College. The X_3 generation was grown in 1941. Among the numerous mutants present in this planting was one which was bush-type and about 12 days earlier than the parent variety. At that time Dr. Down, the bean breeder, was interested in this mutant only because of its earliness; the plants were so small that he saw no value in the bush-type growth habit. In an attempt to transfer the earliness to the parent variety he began a backcrossing program, with selection for earliness, which was continued until 1948. He did not obtain any vine-type plants which were early—the bush type and earliness were completely linked. However, he did obtain bush types which were so much larger than the original mutant that the practical value of this type became apparent. The point is, the new gene had to be transferred to a non-irradiated genic background before its full expression could be realized.

Gene mutations of the type just described, which cause major changes in plant type or maturity, may also need the buffering effect of changes in modifying genes to adjust the organism to them if maximum benefit is to be obtained (17). This might be accomplished by further irradiation or by hybridization with unrelated varieties, followed by selection for the most favorable expression of the new type.

SITUATIONS IN WHICH IRRADIATION APPEARS TO HAVE THE GREATEST POSSIBILITIES

Because of the inherent difficulties involved in producing, sorting out, and using radiation induced beneficial mutations, this method seems appropriate mainly in the following situations:

(1) When the desired gene is not readily available in existing stocks.

(2) When it is possible to screen effectively large populations of second generation irradiated material for the desired gene.

(3) When oddities or monstrosities may have commercial value, as in ornamentals.

(4) In vegetatively propagated species, especially when the breeding cycle is long, as in tree fruits.

A crop which is very well suited to improvement through artificial induction of mutations is oats. With the advent of new races of the crown rust fungus the natural sources of resistance have been depleted. Effective screening techniques have been worked out. Furthermore, oats are naturally self-pollinated, making it easy to select lines homozygous for the desired gene while eliminating undesirable segregates; and also it is a hexaploid species in which the reduplication of genomes tends to buffer the effects of chromosome aberrations. The main difficulty found with oats is that some mutant strains are very difficult to purify, as was mentioned earlier. It is possible that in

some cases the beneficial mutation may actually be a small deficiency duplication (2). Unless pairing is completely regular with respect to the chromosome involved it would be impossible to purify such strains. Any irregularity in pairing would cause the production of off-types.

Ornamentals are in a different category from food and fiber crops, because mutations which would be useless or deleterious in a field crop might be of commercial value in flowers or shrubs. Radiations readily cause changes in flower color, petal and leaf shape, growth habit, etc., and therefore may be of great value to the breeder of ornamentals.

Vegetatively propagated species are often either extremely heterozygous or have long generation times. Others, such as Pangolagrass, are completely sterile. In such crops "mutation breeding" may be more rapid and effective than conventional methods. Spontaneous bud mutations have always been a major source of variation in vegetatively reproduced crops, and it is to the advantage of the breeder to increase the mutation rates by irradiation of cuttings. This has been done successfully in carnations, apples, pears, currants, and blue grass (18). However, caution in interpreting the results of radiation experiments is essential because of the chimeric nature of many vegetatively propagated varieties. Sagawa and Mehlquist (19) found that X-radiation of periclinally chimeric varieties of carnation caused a high percentage of reversion to the original (non-chimeric) type. This kind of change is not genetic, but results from damage to the outer layers of the stem apex, followed by regeneration of the apex from deeper-seated cells which differ genetically from the outer layer.

Irradiation to induce mutations or chromosome breaks also has important applications in the following special situations:

(1) Facilitating the transfer of small chromosome segments carrying desired genes from one species or genus to another (9).

(2) Breaking the absolute linkage between certain genes, such as was done with a complex locus in oats which caused Victoria blight susceptibility and rust resistance to be inherited as a unit (3).

(3) Possibly the chromosomes in newly-developed autopolyploids could be reorganized by causing inversions and translocations to the extent that bivalents instead of quadrivalents would be formed, thus improving fertility (20).

Conversely, there are crops in which irradiation to induce beneficial mutations probably would not at present be profitable. For example, in corn we have an abundance of natural genetic variation readily available, particularly here in the South. Possibly irradiation would assist in such things as changing the chemical composition of the corn plant, but we have hardly begun to explore the existing variation for this character. Furthermore, corn does not lend itself to mass screening of mature plants as well as small grains, because more space is needed per plant and large scale hand pollination would be needed to preserve the genotypes of the plants until evaluation could be made.

Whether the species of plant is naturally self-pollinated or cross-pollinated also has a bearing on the advisability of using radiations to induce beneficial mutations (17). In self-pollinated crops such as oats, spontaneous mutations which might otherwise have accumulated in the population will have been eliminated before they could be found. Also, the natural mutation rate is lower in selfed species than in cross pollinated species, probably because genes favoring a high mutation rate have had a greater evolutionary advantage in the latter.

SUMMARY

Ionizing radiations are very effective in causing mutations and chromosomal aberrations, the great majority of which are deleterious to the plant. A considerable number of beneficial mutants, mainly in self-pollinated crops, have been found in irradiated plant populations. In general it has been necessary to screen rather large numbers of seedlings or plants in order to obtain even a few of the desired type.

Artificial induction of mutations by radiations or other mutagenic agents is a valuable plant breeding tool, supplementing rather than replacing conventional plant breeding procedures. Until more refined techniques are developed it should be used primarily when the goal cannot be readily achieved by conventional methods. One of its major contributions will no doubt be to create genetic variation in self pollinated species where new genes resulting from spontaneous mutations have not had a chance to accumulate. Once the new mutants have been isolated they can be used in regular hybridization and selection experiments in the same way that naturally occurring genes are handled. Another important application of this procedure probably will be to induce new variation in ornamentals and in vegetatively reproduced species.

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SYMPOSIUM: FERTILIZERS

Some Recent Concepts In Nitrogen Fertilization

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FORMS OF NITROGEN AND METHODS OF APPLICATION

The carriers of nitrogen available for use as fertilizer materials in agriculture have not changed since the introduction of urea, anhydrous ammonia and ammonium nitrate in forms suitable for practical useage. There has been considerable change in the methods in which these materials are employed. Prior to the advent of anhydrous ammonia applications, practically all nitrogen was used as mixed fertilizers or dry top dressings. It is true that considerable nitrogen was transported in liquid form and used for ammoniation of superphosphates, but the use of liquid fertilizers directly on the soil is a relatively recent development. Fundamentally, the use of liquid solutions does not introduce any new factors in nitrogen absorption by plants, because the forms—ammonium, nitrate or urea—are still the same as used in dry mixtures. The big factor is the degree of spreading or distribution through the soil by different methods of nitrogen use, the comparative losses of nitrogen by volatilization and leaching, and the significance of burning or toxicity resulting from surface application where materials come in contact with the aerial portions of growing plants.

Deep placement of fertilizers has been given extensive trial, primarily for the purpose of producing deeper rooted plants as drought insurance and for more efficient feeding in the soil profile. In general, the results are quite encouraging. For example, Younts and York (43) showed that concentrating fertilizer in the surface six inches increased development and activity of roots at lower depths as measured by Ca^{45} uptake early in the growing season. Later, roots were more active where fertilizer was distributed through 24 inches.

Irrespective of placement, nitrogen tended to repress root activity below 24-36 inches as reflected by Ca^{45} uptake. Undoubtedly the response of roots and the plant in general is largely determined by the greatest limiting factor for that season and the soil in question. The major factors probably should be considered in the order—first, moisture; second, pH and lime status; and third, mineral nutrients as such.

Volatile loss of nitrogen is a significant factor with solutions containing aqua ammonia in appreciable quantity. Thus, for surface application, only low pressure solutions are acceptable (33). There also is considerable concern for the loss of ammonia from urea solutions applied to the surface, especially if the solutions dry on surface humus carrying sufficient urease enzyme to hydrolyze the urea to ammonium carbonate, but not enough base exchange to hold the ammonia so formed. Available data on this problem is erratic and inconclusive because of the difficulty of carrying out precise experiments to evaluate losses.

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The losses of ammonia from injections of anhydrous ammonia have been studied quite extensively and while quantative data is meagre there is sufficient evidence to show that losses that do take place are primarily the result of blow-out immediately behind the injection chisel. Heavy soils that fracture into coarse clods are more efficient in retention of ammonia than are the sandy soils, not because of a lack of exchange capacity in the latter, but because of the difficulty of rapid replacement of air by the ammonia gas in sandy soils where air pockets are relatively small as compared to the large pockets produced by fracture of the heavier soils (30). If the gas does not immediately jet out behind the injection chisel, then it is efficiently absorbed by the base exchange and retained. There are two further qualifying factors. The first is soil pH and second, soil moisture. Soils of high pH do not retain ammonia as well as the more acid soils, thus a certain amount of slow volatile loss may take place (26). Apparently this is enhanced by the presence of high soil moisture. As the moisture moves to the surface during periods of drying of the soil it tends to carry any loosely held ammonia to the surface with it where loss takes place. The same would be true for equivalent concentrations of ammonia resulting from the application of urea either in solution or dry. Nitrogen applied as neutral salts such as ammonium nitrate or ammonium sulfate are not as subject to volatile loss because the anion and cation are applied together and would tend to offset any tendency toward volatilization even though exchange with bases then on the soil complex takes place.

Any differential leaching resulting from variation in the method of application of a given carrier of nitrogen probably can be ignored. If the potential for leaching is great as is the case with nitrate nitrogen in sandy soils it would remain so regardless of method of application.

Ammonia applied in anhydrous form by injecting is so concentrated that nitrification may be retarded and the development of nitrate with a high leaching potential thus reduced as compared to surface application of aqua ammonia where distribution through the soil is greater (14). The relative leaching potential for urea applied in bands beneath the surface as compared to surface application as liquid probably is of the same pattern because hydrolysis of urea to ammonia even in bands is rapid, resulting in a condition similar to that for anhydrous ammonia. The main difference that must be kept in mind for urea is that of ready mobility before conversion to ammonia, especially under the effect of heavy leaching rains if they occur within a few hours after application. It usually requires one to three days for hydrolysis of urea to ammonia, depending on the concentration of urea. This hydrolysis to ammonia may be retarded in subsoils having low microbiological activity or in sandy soils with appreciable copper residues which tend to inhibit the activity of urease, but for practical consideration these latter factors usually can be ignored.

The advantage, then, of solution application of nitrogen is one of economy resulting from the ease of handling. If the same amount of a given form of nitrogen can be applied cheaper per unit by application as solution, then it is the form to use.

CROP RESPONSE TO VARIOUS FORMS OF NITROGEN

The differential response of a given crop to different forms of nitrogen is not primarily a response to that form of nitrogen per se, but rather a reflection of the effect of soil and other environment on the rates of shift from one form of nitrogen to another. For example, the rate of nitrification of ammonia, the utilization of mineral nitrogen by bacteria during decomposition of crop residues, the mineral fixation of ammonia, and leaching losses are all contributors to end efficiency. Classically, it has been accepted that the ammonia form of nitrogen is relatively more available at neutral pH values and the nitrate at acid soil values, but recent work on potatoes (36) suggests that this has been confused with optimum pH values for nitrification. Ammonia nitrifies rapidly at neutral pH values and not in the strongly acid range. Therefore the general desirability of the nitrate form probably was basic, but confused for ammonia by this effect on nitrification which under normal conditions would produce copious quantitities of nitrate. Wallace (41) using tagged nitrogen showed that nitrate nitrogen was two to five times more readily absorbed by rooted citrus cuttings than was ammonia nitrogen. That nitrate nitrogen is a favored form of nitrogen for most plants is also supported by recent data on correlation of nitrification and crop response, used as a tool for service analysis (15).

Ghosh and Burris (19) studied the utilization of numerous nitrogenous compounds by plants. Organic nitrogen was not as effective as ammonia and nitrate in supporting growth of tobacco, but clover and tomatoes showed considerable similarity to organic nitrogen compounds, and a number of amino acids supported excellent growth. Analysis of N^{15} content of clover and tobacco simultaneously furnished $N^{15}H_4$ and single amino acids indicated that usually the plant first used the reserve of seed nitrogen, then ammonia, followed by amino acid nitrogen.

Numerous tests of foliar feeding of urea show that this compound can be taken in through the leaves of plants, but that any greater efficiency of this method as compared to applying the same amount to the soil is open to question (16).

Recently, considerable attention has been given to the somewhat indirect factors that must be considered in nitrogen fertilization. There has been much concern as to whether or not nitrogen should be used on legumes. Lyons and Earley (25) point out that much of the inconclusive data obtained may be the result of effect of seasonal variation on symbiotic nitrogen fixation, and therefore the cause of erratic response to added nitrogen. Allos and Bartholomew (7) showed that addition of small amounts of nitrogen to legumes increased growth and did not reduce symbiotic fixation, but that with high levels, fixation was less. Viets (34) pointed out that the primary difference in plant response to ammonium sulfate, ammonium nitrate and sodium nitrate appeared not to be the nitrogen, but the effect of the carrier on solubility of zinc in the soil.

Our practices in nitrogen fertilization must also change continually to be in accord with other improved practices which give increased yields, such an improved cultural practices. Hawkins and

Brown (23) found that improved disease and insect control on potatoes required that from 150 to 180 pounds of nitrogen be used for top yields, a range considerably above past recommendations.

AMMONIA FIXATION

The fixation of potassium in difficulty available form by soil minerals has been studied for about thirty years, but only recently has there been developed an appreciation of the possible significance of this process for ammonia nitrogen. At first there was considerable inconsistency of data by different workers using different methods which differ slightly, but which were expected to be approximately equal in effect. Recent careful examination has shown that these methods were different in certain fundamental aspects and the proper interpretation of data obtained by them led to a much greater understanding of the nature and significance of ammonia fixation by the mineral fraction of soils.

Much of the early work was done by Allison and co-workers (1, 2, 3). In this early work they reported that illite and vermiculite clays have considerable capacity to fix ammonia. More fixed ammonia was left following extraction by KCl than NaCl solutions. Calcium chloride removed the most ammonia, probably because calcium tended to expand the crystal lattice. Hot 0.2 *N* KOH solutions removed much less ammonia than did hot NaOH solutions. Montmorillonite clays fixed little ammonia unless preheated. Tests at various times and with different soils showed from 5 to 24 percent of the fixed ammonia nitrifiable within two months time, with lowest values for vermiculite clay. Different clay minerals fixed from 1.6 to 4.0 m.e. 100 grams against KCl extraction. Availability of fixed ammonia to bacteria varied from 0 to 14.8 percent. These values increased only slightly beyond four weeks and only 50 percent of the ammonia nitrified in eight weeks time. With soils incapable of fixation, 75 percent was recovered by nitrification. More recent work by Allison et al (5) showed that normal NaCl removed the most ammonia and KCl the least, with $CaCl_2$, $MgCl_2$ and .05 *N* HCl intermediate and similar. A comparison of NaOH to KOH distillation removal values by the Barshad method (10) showed the latter to give fixation values too high for soils in which fixation was accomplished without heating the soil.

In 1955 Allison and Roller (6) reported that fixation of ammonia ions in a difficultly available form is a process that occurs in soils in which the predominant minerals are vermiculite, illite, montmorillonite and biotite. Illite and meta bentonite, when leached with N ammonium chloride and heated, gave fixation values averaging 1.0 m.e. 100 grams. Preliminary treatment with sodium carbonate increased the fixation to 2.4 m.e. This indicates illite is not responsible for much fixation in soils. Nitrification studies with six montmorillonites showed an average of 32 percent availability of fixed ammonia where extracted with normal $CaCl_2$, and 29 percent where normal KCl was followed by enough $CaCl_2$ to reduce potassium to below the toxic level. They consider that the fixed ammonia can best be defined as that not removed by extraction with normal KCl.

Work reported by Hanway et al in 1956 (20, 21) showed that ammonia fixed in vermiculite and bentonite was completely released by distillation in NaOH solutions, but that small amounts of potassium in the solution blocked this release. Potassium in excess of two K ions per 100 Na ions prevented release of fixed ammonia from vermiculite. Small amounts of fixable ammonia or potassium in the solution prevented release of fixed ammonia when NaCl was used.

A Clarion surface soil which appeared to contain a vermiculate type of clay, fixed one-third of the total absorbed ammonia. Apparently blocking potassium gives low results for fixed ammonia determined by NaOH distillation.

NITROGEN AND SOIL HUMUS

Possibly the most critical factor determining the efficiency of a given form and quantity of nitrogen is its role in the presence of soil humus of the various kinds ranging from raw plant residues or fresh animal manures to more or less stabilized organic matter.

The first process usually considered in analysis of any situation of crop culture and soil is nitrification. If the content of raw residues is high in content of carbon as compared to nitrogen, then nitrogen is in short supply for the decomposing soil mircoorganisms and they will compete with the current crop for any nitrogen concentrate added as fertilizer. If the reverse condition is true, the added nitrogen can convert to nitrate and, in addition, nitrate will be freed by mircoorganisms breaking down the nitrogen rich humus, depending on how much exists. These processes have received much attention recently in an attempt to better understand this balance between biologically fixed nitrogen and available nitrogen. We now know that the secret of soil fertility largely lies in proper evaluation of this biological fixation and release cycle for each set of conditions encountered in crop production.

Temperature is probably the greatest single factor controlling rate of nitrification, other factors being equal. Renewed interest in temperature conditions influencing nitrification came about as a result of off-season fertilization trials. If nitrification in cold months is sufficiently retarded, it should be possible to apply ammonia nitrogen in the fall, for example, without chancing the serious leaching losses that would occur if a readily mobile form such as nitrate was used or developed by nitrification. Recent work by Sabey et al (28) and Anderson and Purvis (8) indicated that nitrification dropped off very markedly at about 50 degrees F. although some nitrification continued to take place even at relatively low temperatures. Frederick (17) reported that the greatest increase took place between 7 and 15 C. for the soils he studied. The maximum was approached between 27 and 35° C.

Denitrification, the reduction of soil nitrogen to volatile atmospheric nitrogen, again is receiving considerable attention because use of tagged nitrogen has provided a new tool for reattacking this problem. Hauck and Melsted (22) have presented some aspects of the problem of evaluating denitrification in soils by use of the mass spectrometer and the infra-red spectrophotometer. They accounted for

89 to 100 percent of the nitrate nitrogen added to a laboratory soil. They collected 3.9 and 14.4 mg. of nitrogen as N_2 from unlimed and limed soils respectively where 226.1 mg. had been added as nitrate. Nitrogen collected as N_2O was 26.4 and 6.5 mg. respectively. With this type of approach a true evaluation of field practices in nitrogen economy should soon be possible. Wahhab et al (38, 39) have reported that light has a marked effect in increasing the interraction between ammonia and nitrate ions. Losses of nitrogen as N_2 increased as the pH value of the medium increased, and increasing the concentration of the ammonia ions up to a certain point increased losses. In low concentrations ammonia and nitrite did not interact in either aqueous media or alkaline soils. In highly alkaline soils interaction was high at concentrations of ammonia and nitrite brought about by desiccation.

Chapman and Liebig (13) state that nitrite was found to accumulate under neutral or alkaline soil conditions if nitrogen fertilization is enough to produce a considerable concentration of ammonia ions. In cold soils nitrite may persist for several months. More nitrite appears to follow the use of urea than other sources. This agrees with results reported by the writer (35). Urea is particularly effective because it is a fully alkaline source of nitrogen once hydrolysis to ammonia takes place, which usually occurs within two days time (37). Walker *et al.* (40) studied the fate of N^{15} nitrate and ammonia nitrogen applied to grass and clover. They could not account for approximate 30 percent of the added nitrogen in the crop or soil and concluded that it was lost by denitrification. They obtained slightly higher losses from potassium nitrate than from ammonium sulfate. Jansson and Clark (24) reported loss of nitrogen in decomposition of alfalfa but not with oat straw in the presence of inorganic nitrogen. They state that vigorous bacterial activity and alkaline reaction are necessary for extensive denitrification of nitrate. Nitrite toxicity appeared to be an important ecological factor in preventing bacterial growth and denitrification in acid substrates.

Broadbent and Stojanovic (12) studied the effect of partial pressure of oxygen on some soil nitrogen transformations. Immobilization of added nitrogen occured whether or not ample nitrogen was available to the soil population. Reduction of nitrate to ammonia was neglible at all oxygen concentrations although slightly higher under anaerobic conditions. Denitrification was inversely related to partial pressure of oxygen but was of appreciable magnitude even under fully aerobic conditions. There was no evidence of nitrogen loss when ammonia was added. The above supports the theory that nitrous oxide in the atmosphere arises from the soil and that denitrification is of major importance in the nitrogen cycle.

It appears obvious that denitrification losses of nitrogen are a serious problem, but that the use of labeled nitrogen will serve as an excellent tool in evaluating various processes and reducing denitrification wherever practical to do so.

The use of labeled nitrogen and other improved procedures have also helped materially in the study of nitrogen transformation from mineral to organic state and the reverse. A pertinent question in recent years was whether or not adding nitrogen produced more humus.

The various processes are difficult to evaluate. The relatively recent theory that nitrogen as such has value in producing a more resistant or stable type of humus apparently must be accepted with caution or discarded (4). The real effect of nitrogen is to increase crop residues by encouraging greater crop growth. Crop residues of the readily decomposable type do not generally have any material effect on increasing persistent organic matter, but residues such as are produced by sod crops are of significant value (9). However, Russell *et al.* (27) indicated measurable effect of long time usage of heavy applications of manure. The effect of nitrogen in the humus cycle is of primary value on a short time basis, for example its effect on the crop to which applied or on the crop immediately following.

Recent reports by various workers (11, 18, 29, 31, 32), in general supports the conclusion that the amount of available nitrogen released following addition of a nitrogenous material depends on the carbon-nitrogen ratio. In a study of the availability of nitrogen in various materials it was found that alfalfa tops were more efficient than red clover as a source of nitrogen for corn. Soybean tops had no effect, and hulls depressed the yield. The nitrogen of alfalfa was only 34 percent as efficient as that of ammonium nitrate. In the second season the efficiency of alfalfa was only 7.5 percent that of the first, showing relatively little carry over effect. In certain of the tests fertilizer nitrogen had essentially disappeared from mineral form by the boot stage of oats. Where either ammonia or nitrate was added with wheat straw, rapid immobilization of nitrogen took place. However, with corn leaves of high nitrogen content immobilization of ammonia only took place. In the two to six day period, 54 pounds of nitrogen per acre per day was immobilized by wheat straw. The maximum occured in the zero to two day interval with corn leaves because maximum microbiological activity would be attained earlier as a result of the energy material being more available. It is interesting to note that even high-nitrogen material like corn leaves immobilized nitrogen.

Wallace and Smith (42) reported that about 50 percent of the nitrogen of finely ground avocado leaves disappeared in 100 days. Three fourths was lost from orange leaves. Simultaneously there was no nitrification with the former but considerable with the latter even though both materials originally had the same nitrogen content.

There is little doubt but that increased knowledge of processes of nitrogen transformation in the soil is showing the importance of such knowledge, and that at the same time it is reducing the concern for the original form of nitrogen applied as fertilizer.

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Impact Of Radiophosphorus On Fertilizer Phosphate Research*

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Phosphate fertilizer research dates back to the historic experiments of Lawes and Gilbert over 100 years ago. During the past 30 years soil phosphorus research has developed rapidly, and during the last 15 years there has been an increased use of phosphate fertilizer in the United States accompanied by an expanding area of fertilizer phosphate research.

Some of the reasons for this expansion are: (1) the need for better pasture and forage crop productivity on millions of acres of grasslands and arable soils converted to pastures; (2) the realization of higher yield possibilities with improved varieties of field and forage crops; (3) the accelerated use of irrigation water in the humid areas as well as in the drier western regions; and (4) the manufacture of new types of fertilizers, many of them of concentration high enough to warrant shipping to greater distances from sources of raw material such as rock phosphate. These trends have been accompanied by improved breeds of animals for meat and dairy products.

These developments have been featured by extensive research in the relation of soil fertility to plant composition and quality and the resultant effects on animal and human nutrition. Since this paper reviews some of the literature relating to the use of radiophosphorus in research with phosphates in crop production, the literature referred to dates back about two decades.

As early as 1939 the cyclotron began to produce radiophosphorus in amounts sufficient for small scale plant and animal experiments in laboratories and greenhouses. At once it became an invaluable research aid because the phosphorus in plant nutrients and animal feeds could be tagged or labeled with a minute amount of radiophosphorus whereby an accurate evaluation could be made of the passage of a particular phosphorus compound through soil, plant and animal. This makes it possible to do what cannot be done without radiophosphorus, namely, to measure quantitatively the amount of labeled introduced phosphorus as apart from the phosphorus already present in the soil, plant and animal. For fertilizer research it thus became possible to ascertain more definitely factors such as the availability of the phosphorus of a particular phosphate when added to a particular type of soil and as influenced by soil management practices such as associated fertilizer elements, liming, type of crop and crop sequence.

This concept of the ability to differentiate between two sources of phosphorus, one labeled with P^{32}, is modified somewhat by the knowledge that phosphate ions exchange with ions of soil minerals (9, 10, 38)[1] and that the chemical form of radiophosphorus may be

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[1]References in parentheses refer to the literature cited section.

somewhat different from that of non-radioactive phosphorus (12). This latter factor is so slight as to be of no importance in fertilizer research and the phosphorous anion exchange also is considered not to be of sufficient magnitude, at least in most soil types, to introduce any error of consequence in the measurement of the ratio of the labeled phosphorus taken up by the plant to that present in the soil.

For several years the main source of radiophosphorus was that produced by the cyclotron, and although the amount was small, it was sufficient for a large number of qualitative and quantitative experiments with soils and plants. The efficiency of very small amounts of radiophosphorus is evident from the fact that it can be measured with 1% accuracy (18) when present to the extent of 0.46×10^{-15} gms. or a forty-six millionth of a microgram. Thus the tracer method is about 46 million times as sensitive as a gravimetric method. Moreover, the electrons emitted by P^{32} have an energy sufficient to penetrate 2.8 mm. of aluminum. This type of radiation can be measured conveniently in a sealed Geiger tube and by the same token radioautographs can be obtained on sealed x-ray films with little difficulty.

Because of limited supplies of P^{32} early work with the isotope was limited to small scale experiments with small samples of soil or with plants growing in solution cultures. However, these early but small amounts of cyclotron P^{32} were of separated phosphorus P^{32} admirably suitable for well controlled experiments involving low concentration of phosphorus. These early experiments with cyclotron P^{32} served well to establish more definitely the fundamentals of the behavior of nutrient phosphorus. More basic knowledge of that nature makes possible a better understanding of the role of phosphorus when added as various phosphates and mixtures to complex soil systems.

Some of the first research with P^{32} occurred at the University of California, where it was first produced by a cyclotron in usable amounts. Thus Stout and Hoagland (44) published a paper in 1939 recording measurement of amount and rate of transfer of labeled phosphorus from roots to various parts of plants. Arnon and coworkers (1) reported on the use of P^{32} as an indicator of phosphorus absorption of tomato fruits at various stages of development. Biddulph and associates (3) reported on the translocation of P^{32} in the phloem of the cotton plant and on the uptake of P^{32} by bean plants (4) in relation to the pH and iron content of the solution. Comar and Neller (8) determined the uptake of P^{32} by oats growing in jars of soils ranging from fine sands to clays and found that uptake correlated with the amounts of P^{32} extractable from the soil. Caldwell (6) used P^{32} in translocation studies of squash plants and described methods of making radioautographs of the labeled phosphorus as found in different parts of the plant.

Space does not permit review of all work reported with cyclotron P^{32} before it was produced in an atomic pile in amounts large enough for field studies. However, some attention should be given to techniques of measurement that were devised. In some of their early work, Ballard and Dean (2) used an electroscope for P^{32} measurements. The Geiger Muller counter tube connected to a suitable recording device soon became the standard type of equipment (16). In some instances the labeled phosphorus was measured in solution (8) and

in other cases the phosphorus was precipitated as magnesium ammonium phosphate deposited on filter paper sections held in place by circular aluminum clamps (23). Later when supplies of P^{32} became more plentiful MacKenzie and Dean (24) devised a method of compressing ground plant material in a laboratory press to form pellets, the P^{32} activity of which could be measured directly by controlled placement of a pellet below a Geiger tube. This serves as a time-conserving method, provided the phosphorus is of high enough specific activity. Otherwise, it has to be separated and the P^{32} content measured either in solution or after precipitation of the phosphorus.

About 10 years ago P^{32} began to be produced in the atomic pile at Oak Ridge, Tennessee, in amounts sufficient to label fertilizer phosphates in large enough quantities for field plot experiments. Radiophosphorus has a half life of 14.3 days, resulting in an activity strong enough to be accurately measured for three to four months after production of the P^{32}. This is enough time to incorporate the P^{32} into a phosphate fertilizer, to make the soil treatment with the labeled fertilizer and to obtain samples of the planted crop or forage at fairly mature stages of growth for quantitative measurements of the uptake of phosphorus of the labeled phosphate.

The problem of labeling fertilizer phosphates with P^{32} was solved by an excellent cooperative arrangement whereby the Atomic Energy Commission allocated supplies of P^{32} to the U. S. Department of Agriculture at Beltsville. A special processing plant was set up there with adequate facilities for the safe incorporation of tracer amounts of P^{32} into phosphates produced from raw rock phosphate. These labeled phosphates were shipped to state experiment stations and other research agencies staffed and equipped to conduct research with the materials. The U. S. Department of Agriculture Division of Agricultural Engineering also cooperated by devising a belt type of fertilizer distributor (Figs. 1, 2), shielded and calibrated for safe and accurate distribution of the labeled fertilizer. For purposes of distribution and cooperation, the United States was divided into the southern, northeastern, north central and western states. In the 13 southern states radiophosphorus fertilizer research was aided by a grant of funds by a phosphate research committee of fertilizer companies.

One helpful feature of radiophosphorus research is that it aids in a differential measurement of fertilizer phosphorus availability to a crop that may not show growth response to phosphate. Thus, on land that has been phosphated for a number of years with no yield differences in an experiment, no effect of phosphate might be noted; but if the phosphate is labeled with P^{32} the percent uptake of phosphorus can be determined. These uptake data are often of considerable value in a study of a phosphate and the factors affecting the availability of its phosphorus, such as liming, leaching and interaction with other elements. Moreover, the amount of phosphorus found in crops after deducting the labeled phosphorus is a measure of the available residual and soil phosphorus.

In Florida practically all soils in their native state are deficient in phosphorus except the Arredondo-Kanapaha group. Large areas are still uncropped and P^{32} experiments on these permit a type of study of residual fertilizer phosphates not possible with land that has been

Figure 1.—The belt type fertilizer distributor build for safe application of radioactive materials. Transparent plastic boxes with hinged covers are placed over each of the six belt distributors. Temporary plywood windbrakes are on this machine. The distributor was built by J. G. Futral of the Georgia Agricultural Experiment Station with funds contributed by the Phosphate Fertilizer Research Committee of the southeastern states.

fertilized for a long time with unknown amounts of phosphate. Thus, it was found that the fixation of phosphate phosphorus increased with increasing content of clay in the soil (29) and that in sandy loam soils high in iron and aluminum the phosphorus of rock phosphate is about one-fourth as available as that of superphosphate (31) Robertson and co-workers (37) found that liming up to pH 6.0-6.5 soils that are relatively low in phosphates increased the availability of the phosphorus of applied phosphates in soils high in sesquioxides but had little effect in soils low in sesquioxides.

Stelly and Morris (43), working with Cecil sandy clay loam, one of the most important agricultural soils of the Piedmont Plateau region, found that uptake of phosphorus of superphosphate by cotton was about 28 percent of the plant phosphorous where no phosphate had been applied two years previously. Where phosphate had been applied, the percent uptake of labeled phosphorus decreased progressively with increase in rate of application. Engsminger and Pearson (11) determined the residual effects of phosphates on yields. P^{32} uptake and extractable phosphates. Their experiments were on Decatur

Figure 2.—Front view of machine in Fig. 1 showing distributor pipes leading from the six belts. The attachment for deep placement of fertilizer is also installed on the machine.

and Greenville soils that had grown cotton, corn and vetch in rotation for 16 years. Jacob and associates (20) found that the percentage of applied superphosphate phosphorus utilized by potatoes in Sassafras and Bladen silt loams ranged from 4.2 to 14.5 percent when applied at the rate of 100 pounds P_2O_5 per acre. Spencer (40) used radiophosphorus to measure the availability to citrus seedlings of superphosphate phosphorus accumulated in Lakeland fine sand and found that the phosphorus of the subsoil was as available as that in the surface 6 inches. He obtained good correlation between "A" value phosphorus and the amounts extracted with NH_4F. From a study of P^{32} phosphorus uptake by grasses, Birch (5) found that the phosphorus removed from soils was in direct relationship to degree of base saturation.

Fried and Dean (15) pointed out that knowledge of percent uptake of phosphorus resulting from labeled phosphate applied at a given rate permitted calculation of percent uptake of phosphorus of the phosphate applied at other rates. The "A" value determined from

their formula is a good measure of the availability of phosphorus in a soil, provided the labeled phosphate has been well mixed with the soil as is possible in a greenhouse experiment or in a well incorporated broadcast application in the field. The "A" value formula was used (31) in evaluating the uptake of phosphorus of superphosphate disked into plots that had been fertilized with rock phosphate and superphosphate.

The labeling of phosphates with P^{32} can serve as a research tool in many ways. Thus, McAuliffe and co-workers (25, 26) labeled phosphates of sheep manure and determined availability to plants of the organic and inorganic forms of phosphorous. White and associates (45) determined the utilization of phosphorus of green manure crops by the succeeding crop, using radiophosphorus. Fuller and associates (13) labeled crop residues with P^{32} and found that availability of the phosphorus to barley on Mohave clay loams was affected by the maturity of the crop residue as well as its kind, P content and time of contact. The threshold P content of a crop residue above which the P of the residue was wholly immobilized by soil organisms was 0.2%. Fuller and Nielsen (14) labeled wheat straw and wheat straw compost with P^{32} and obtained data to indicate that there is no particular advantage in adding liquid phosphoric acid directly to straw before incorporating it in calcareous soils, over the practice of applying the fertilizer and straw residues separately. Shirley and coworkers (39) traced labeled phosphorus through soil, plant and animal and were probably the first to do this with forage labeled with fertilizer phosphorus grown in the field in sufficient amounts to be fed to an animal as large as a yearling steer.

A number of experiments have been conducted utilizing P^{32} in a study of effect of placement of phosphate on uptake of phosphorus. Thus, Woltz and associates (46) found that tobacco in Cecil and Enon sandy loams did not utilize phosphates in side dressings as well as when placed in bands or when mixed in the row, especially under dry soil conditions. Stanford and Nelson (41) showed that corn in Clarion-Webster soils (Iowa) utilized phosphate better when placed in bands on one or both sides of the seed than when placed above or below the seed. Working with sugar beets, barley and wheat in calcareous fine sandy loams in Colorado, Olson and co-workers (34) found that there was greater uptake of the more soluble phosphates in band placement than of soluble phosphates with rototiller mixing. Nelson and associates (32, 33) found no yield differences of corn and cotton as to placement of phosphate in Norfolk sandy loam but the P^{32} uptake data showed band placement to be better than broadcasting. In Florida (30) labeled superphosphate was applied on the soil surface of sodded grasses on Marlboro and Ruston fine sandy loams. Uptake of phosphorus was distinctly greater than with applications 3 and 6 inches below the surface. Lawton and co-workers (21), working with loamy Michigan soils, found that absorption of P from superphosphate in meadow hay was highest for placement in the top 3 inches, intermediate for the 6-inch depth of placement and low for lower depths of placement.

In recent years a series of phosphates has been produced having differing amounts of phosphorus in water-soluble and water-insoluble

form. Hill and co-workers (19) labeled a number of these phosphates with P^{32} and processed them into pellets of different sizes. In a laboratory study of these, Lawton and Vomoil (22), using sandy and loamy soils, found that 50 to 80 percent of the water-soluble phosphorus moved out of the pellets in 24 hours with more rapid movement in wet soils. The phosphorus moved a maximum of one inch out into the soil and the larger the granule or pellet, the more extensive the migration. Using pelleted 12-12-12 fertilizers, it was found (27) that growth and uptake of phosphorus by oats in Leon fine sand (Florida) was not influenced much by degree of water solubility of the phosphate. Growth and uptake were reduced on Red Bay fine sandy loam for fertilizer containing phosphorus of low water solubility. Owens (35) found migration of phosphorus from these pelleted 12-12-12 fertilizers in sandy to loamy soils in Michigan to be highest where the most phosphorus was in water-soluble form, particularly for large-sized pellets. Yield of sugar beets was increased but with no significant difference between pulverant and granular type fertilizer.

Radiophorphorus has been used to some extent in evaluating phosphates produced by the Tennessee Valley Authority for experimental purposes. Thus, radioactive superphosphate was used (28) to compare the availabilities of residual phosphorus from fused tricalcium phosphate and from superphosphate. Uptake by oats in Leon fine sand was less where superphosphate had been used. The reverse was true for Red Bay fine sandy loam, a soil of high fixing power for phosphorus. This indicated that the phosphorus of superphosphate went into solution more quickly than that of tricalcium phosphate and was more quickly immobilized by fixation activities in the soil. Caldwell and co-workers (7) applied various phosphates annually to Kenyon silty clay (Minn.) of pH 6. After seven years the availability of the residual phosphorus to hay, wheat and corn determined by a labeled superphosphate application was found to be distinctly greater for calcium metaphosphate, superphosphate, liquid phosphoric acid and tricalcium phosphate than for rock phosphate. Starostka and co-workers (42) used Evesboro sandy loam and Davidson clay loam (N.C.) in ascertaining that 14-20 mesh granules of superphosphate and 28-35 and −35 mesh granules of dicalcium phosphate were the best mesh sizes for the respective phosphates for wheat based on total phosphorus uptake, yields and percentage of phosphorus derived from the fertilizer. Pesek (36) found that the finer −40 mesh calcium metaphosphate supplied a greater percentage of phosphorus to clover and grass in Ida silt loam (Iowa) than −10 mesh material. The phosphorus of the superphosphate was somewhat more available than that of the calcium metaphosphate. Caldwell and associates (7) determined that superphosphate was more effective in supplying phosphorus to alfalfa on Waukegan silt loam (Minn.) than fused tricalcium phosphate but that the difference decreased with time. Hall and co-workers (17) found that corn on Norfolk fine sandy loam (N.C.) derived more phosphorus from superphosphate and calcium metaphosphate than from tricalcium phosphate. With cotton on a high phosphorus soil the lowest uptake was from dicalcium phosphate and the highest was from calcium metaphosphate followed by superphosphate.

Subsequent to the preparation of this paper, an article by Lipps and associates[2] appeared in the September 1957 issue of Soil Science dealing with the use of radiophosphorus in characterizing the root activity of alfalfa. The authors placed radioactive superphosphate in vertical-lateral patterns in a chernozernic soil in Nebraska. They found three zones of root activity, one of high activity in the surface soil, a second of low activity in an unfavorable chemical environment between 2 and 4 feet and a third of moderate activity in moist soil above the water table. Their article, together with the quoted references, gives a good comprehension of the use that has been made of P^{32} in studies of distributions and activities of roots of crops.

SUMMARY

This paper reviews some of the literature relating to research with radioactive phosphorus in the role of phosphorus in plant nutrient salts and fertilizer phosphates. Cyclotron-produced radiophosphorus (P^{32}) became available about 1939 in amounts sufficient for small scale experiments. About 1947 P^{32} was first produced in a uranium atomic pile in amounts sufficient to label phosphates for field crop experiments.

Radio phosphorus continues to be an important research tool in nutrient phosphorus research. It supplements other research methods of evaluation of phosphates and is unique in one category in that it makes possible accurate quantitative tracing of a particular labeled phosphate as apart from the phosphorus already present in the soil, plant and animal.

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The Behavior Of Potassium And Potassium Fertiliers In Florida Soils*

NATHAN GAMMON, JR.**

Potassium is essential for agricultural production in Florida. The figures for the 1955-56 crop year show that the equivalent of 101,431 tons[1] of K_2O were applied to Florida soils. The application of such a large tonnage to the soil proves the general acceptance of the importance of potassium, but since being generally accepted often means being carelessly taken for granted, it would be well to review the nature of the behavior of potassium in the soil. The purpose of this paper is to review some of the important facts about potassium, particularly as they relate to Florida soils.

The total potassium in Florida soils, as judged on the basis of representative Alachua County soils (6), will usually range from 300 to 500 pounds per acre 6 inches of soil, however, exceptions which range from in excess of 8000 to less than 80 pounds per acre are not infrequently encountered. About 90% of this potassium is non-exchangeable and, for all practical purposes, is unavailable for plant use. The remaining 10% of exchange potassium is not sufficient in most Florida soils for production of economic crops without the addition of fertilizer potassium.

Potassium is an active base and competes with calcium, magnesium, hydrogen and to a lesser extent, sodium, iron, aluminum and other metals for positions on the base exchange complex of the soil. The degree of retention of any one of these ions is a function of its activity, size, valence and degree of hydration (1) in addition to the the relative number of ions present and the kinds of clay and organic matter making up the exchange complex. It is necessary to remember that although potassium fertilizer is added to the soil, any permanent addition is the result of an exchange reaction. The addition of a potash salt such as potassium chloride must result in the loss of some other base or hydrogen if the potassium is to remain behind on the soil exchange complex. In this respect the use of lime in soil management has an important influence on the amount of potassium one can add to the soil as illustrated by the following examples.

The first effect of liming the soil is to reduce the exchangeable potassium. This is primarily a mass effect where the vastly greater number of calcium ions simply replace the potassium ions on the exchange complex. Table 1 shows the typical effect of liming on the exchangeable potassium. Part of the exchangeable potassium was simply displaced from the exchange complex and moved down the soil profile in the drainage water.

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[1]Florida State Department of Agriculture Summary 1955-56 Fertilizer Consumption.

Table 1.—Loss of Exchangeable Potassium One Year After Liming a Leon f.s.

Treatment	Soil pH	Exchangeable K in ppm.
No lime	4.67	26
2.7 tons lime/acre	5.96	8

Although the first effect of lime is to reduce the exchangeable potassium, the second effect is to increase the percentage retention of applied fertilizer potassium. This is because potassium can replace calcium from the exchange complex much more readily than it can hydrogen. Table 2 shows how an increased percentage of the fertilizer potassium was retained over a three-year period on the soils adjusted to higher pH levels. This is even more striking when one remembers that the first effect of lime as shown by Table 1 is to reduce the amount of exchangeable potassium.

Table 2.—Retention of Fertilizer Potassium in the Soil Under a Tobacco Shade Three Years After Soil pH Adjustments.

Soil pH	Exchangeable K in ppm.
5.26	190
5.57	227
5.84	267
6.24	272

One must not infer from the data in Table 2 that the exchangeable potassium level will continue to increase simply because of the increase in soil pH. A higher level is reached but the eventual result is a new equilibrium point dependent upon all soil management factors, rate of fertilization, crops grown, and rainfall.

Annual potassium applications to Florida soils range from 30 pounds of K_2O per acre or less on some pastures to 800 pounds per acre on some excessively fertilized soils used in celery production. Despite a total 800 pounds per acre of K_2O applied in February and March to a celery field near Sanford, Blue, et al (2) found that most of the fertilizer potassium had leached from the top 30 inches of soil by late August. They also found no appreciable accumulation of potassium in the top 30 inches of the soil in fields that had been heavily fertilized for celery production for over 10 years. Similar observations have been made by Robertson et al (7) for field crops and by Gammon and Blue (5) for pastures. In these latter observations, there was some accumulation of potassium in years of unusually low rainfall when the salts were obviously not all leached out. Subsequent years of normal rainfall removed the residual salts as well as those from the fertilizer additions made during those years.

Laboratory studies on potassium leaching tend to confirm these field observations. Over 90% of the fertilizer salt equivalent applied to the surface of a 5-inch column of soil was recovered in the first inch of distilled water leachate to pass down through the column. Such a study on a "dead" soil, however, only indicates the maximum possible rate of loss. Such losses are undoubtedly retarded by active soil microorganisms, plant roots and the moisture movement characteristics of the soil.

Moisture movement within the soil is an extremely important factor in the rate of potassium leaching. In the laboratory experiments, moisture moved downward only; in the field, moisture moves downward during a rain, but tends to move upward at other times when water is lost at the soil surface through evaporation or through plant transpiration. Any factors, such as high water tables, perched water tables, semi-impervious hardpans, plow pans, and clay pans, that tend to slow the rate of downward water movement will slow the leaching of potassium at least to the extent that the water movement is reduced. Likewise, the nearer this water is held to the surface, the more likely it is to move upward to replace water being lost near the surface by evaporation and transpiration. This reverse flow of soil water also reverses the movement of the potassium salts being carried by the water.

Most annual crops in Florida that require heavy potash fertilization are grown during the cool, dry season and supplementary irrigation is usually required. Under such conditions of limited soil moisture movement, most of the applied potassium fertilizer salts will remain within the rooting zone of the crop for the entire period of growth. Although fortunately they are rather infrequent during the vegetable growing season, rainfall totaling three inches or more may occur over a period of less than 48 hours. Under such conditions, much of the fertilizer potash may be leached from the rooting zone of the annual crop. A side dressing of both potash and nitrogen following a leaching rain may be highly beneficial for a crop that is not already well along towards maturity. The deeper rooted perennial crops are generally less sensitive to leaching rains, probably because a rain of much greater intensity would be required to move the fertilizer potash out of the rooting zone.

It would appear that the major source of potassium for heavily fertilized crops on light textured soils is directly from the fertilizer salts rather than from the exchange complex. Soil management practices which tend to conserve potassium on the exchange complex are important in that they retain more reserve exchangeable potassium against the leaching of an excessive rain. However, most of the potassium for the production of the crop must come from regular applications of potash fertilizers. Lightly fertilized grass and grass-clover pastures are more dependent upon small reserves of exchangeable potassium in the soil for proper growth. But even on a crop of this type, that is a relatively efficient user of potassium, annual applications of potash fertilizer are necessary to maintain satisfactory levels of growth.

Many soils contain clays which have the property of "fixing" potassium, that is, converting it into a form of very limited availability to plant roots. Preliminary surveys (3, 4) indicate that such clays do

not predominate in most Florida soils. Even though the clays in the Bladen and Tifton soil series contained appreciable quantities of vermiculite and montmorillonite which are capable of potassium fixation, the usual amount of clay present in the surface horizons was too small to appreciably influence potassium fertilizer practice or responses.

The major source of potassium for Florida fertilizers is muriate of potash and sulfate of potash is the second most important source. Other minor sources include sulfate of potash-magnesia, nitrate of soda-potash, potassium carbonate, hardwood ashes and manure salts.

For most crops, price alone is the factor that determines the source of potassium to be used. However, certain crops, especially those in the solaneaceous group, have a low tolerance for chlorides and the sulfate source is sometimes specified in order to reduce the amount of chloride in the fertilizer. When magnesium also is required in the fertilizer, sulfate of potash-magnesia is frequently used. Laboratory leaching studies have shown that slightly more potassium is retained by the soil from potassium chloride than from potassium sulfate, but the difference seemed too small to be of agricultural significance.

The reaction of potassium carbonate with the soil differs from the exchange reaction of chloride or sulfate salts in that the potassium is absorbed directly on the exchange complex with a release of CO_2 and H_2O. Only relatively inactive carbonic acid is left in the soil so that initial leaching of potassium from this source is practically zero. However, excessive potassium applied to the soil in this manner causes the entire soil colloidal system to deflocculate. This source of potassium in small quantities is an excellent way to increase the potassium level in the soil, but its excessive use on light soils would tend to destroy the entire exchange complex because the deflocculated clay and organic matter making up the complex are readily moved into the subsoil by leaching rains.

The reaction of the potash in hardwood ashes would be similar to that of potassium carbonate. Manure salts are simply low analysis muriate of potash sources and, hence, will perform in the soil in the same manner as potassium chloride.

SUMMARY

The usual fertilizer potash sources applied to Florida soils, for the most part, remain in the soil as soluble salts, moving along with the soil solution and eventually leaching out with heavy rains. Annual applications of potash fertilizers are necessary to maintain production of practically all crops grown in Florida. The role of lime in the retention of more potash on the soil base exchange complex was demonstrated.

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Fertilizer Development In The TVA: New Processes And Agronomic Implications

George Stanford and T. P. Hignett*

The various phases in TVA's research and development work include (1) chemical research, for the studies of new processes and compounds and collection of data on the properties of chemical compounds involved in fertilizer production, (2) chemical engineering development, including small-scale and pilot plant studies to find practical and economical methods of carrying out new processes, and (3) large plant operations, to obtain conclusive technical data and complete the development of new processes, to demonstrate the processes, and to create a demand for new products. Parallel to these research and development phases, the effectiveness of new products is tested in the greenhouse, in field plot tests, and, finally, on the farm. Other phases of the program include studies of the economics of new processes and of the economics of fertilizer use.

The present paper presents recent advances in processes for making conventional fertilizers and in research and development on experimental fertilizers that are not presently being produced commercially. The significance of these technological developments in relation to nutrient availability to plants also will be considered.

I. GRANULAR FERTILIZERS PRODUCED FROM CONVENTIONAL RAW MATERIALS USING THE TVA CONTINUOUS AMMONIATOR-GRANULATOR

A. The Continuous Ammoniator-Granulator

There are about 100 large-scale continuous ammoniation-granulation plants in operation in this country that utilize principles of the pilot plant designed and operated by the TVA at Wilson Dam, Alabama. The central unit in the pilot plant, the continuous ammoniator, was developed and patented by TVA. This unit, shown in Figure 1, is discussed in various publications (6, 7, 8, 40). Fluid ingredients (water, ammonia and ammoniating solutions, and acids) usually are introduced at controlled rates through submerged distributors placed in the deepest part of the bed. Solid raw materials and recycle fines are fed through volumetric feeders (hoppers) onto variable-speed belts. The formulations are chosen to permit adequate control of the amount of liquid phase, solid phase, and temperature at levels desired to achieve proper granulation. Auxiliary means of controlling these variables include provisions for (1) recycling of fines, (2) introducing steam or water, and (3) directing jets of air against the bed.

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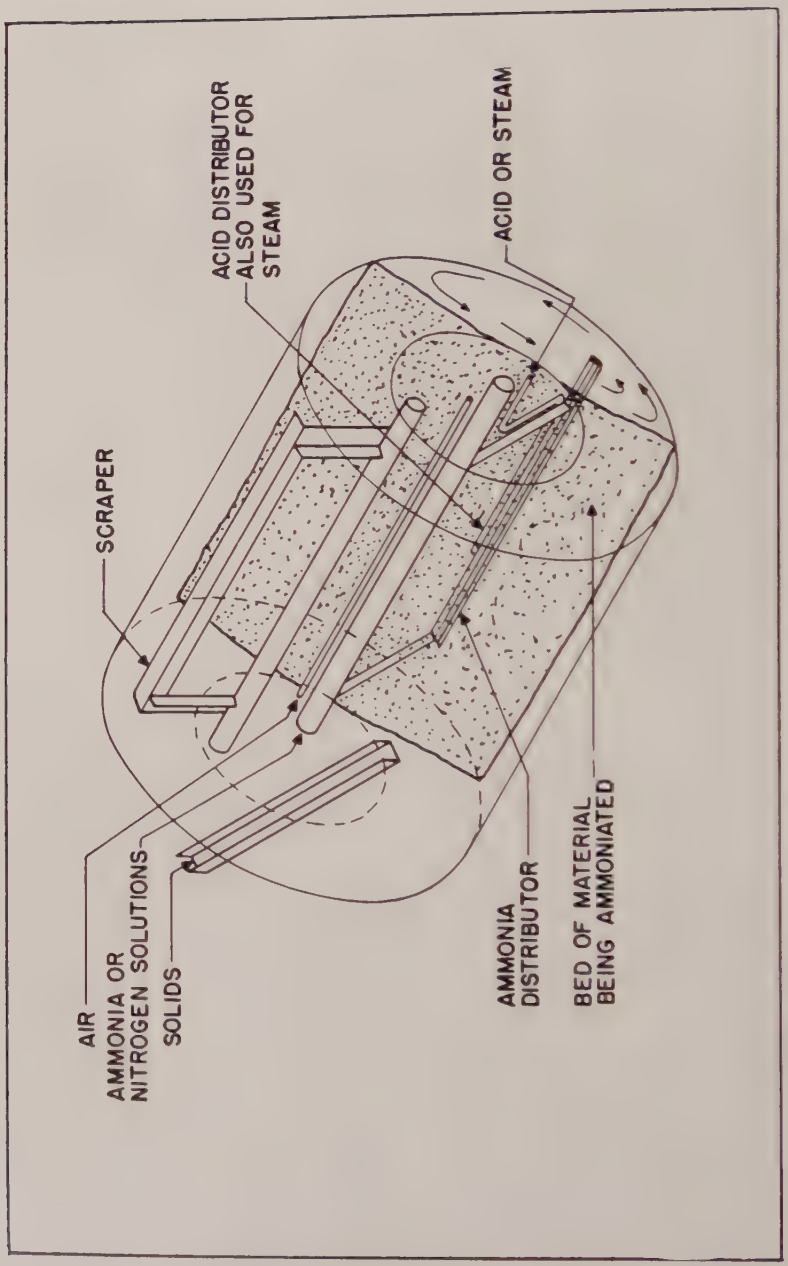

Figure 1.—Pictorial view of the continuous ammoniator used in the TVA pilot plant (6).

A general sketch of the pilot plant is shown in Figure 2. Material passes by gravity from the ammoniator to the granulator. Hignett and Slack (11) state that, typically, most of the granulation takes place in the continuous ammoniator when the formulation is selected to

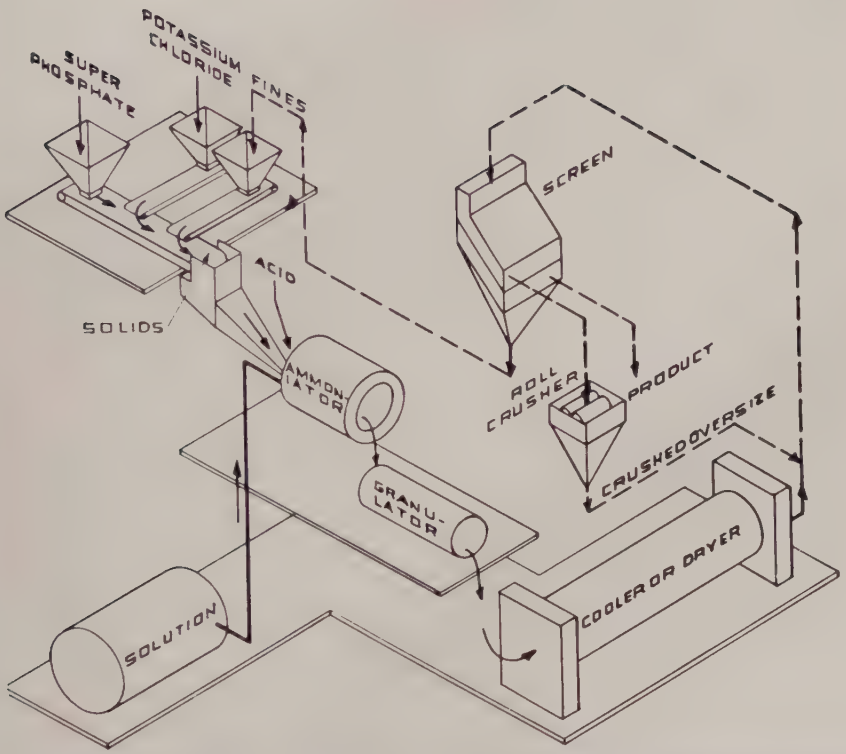

Figure 2.—The TVA pilot plant used in research on processes involving continuous ammoniation and granulation of fertilizers.

provide the right combination of liquid phase and temperature. In some instances, however, the granulation step is completed in the granulator. Here, also, firming and compaction of granules takes place. The third rotating drum in the train may serve as a cooler and dryer using a countercurrent flow of air, or as a dryer when heated air is supplied.

Material then is conveyed to vibrating screens where the onsize fraction ($-6+16$ or $-6+28$ mesh size, Tyler) is collected. The undersize fraction is recycled to the ammoniator. The oversize fraction is either crushed and returned to the screens or pulverized and recycled to the ammoniator.

The versatility of the equipment is illustrated by the fact that it may be used with various modifications to produce granular superphosphates, nitric phosphates, ammonium phosphate-nitrates, and a wide variety of granular mixed grades.

B. Granulation of High-Analysis NPK Fertilizers

Prior to the development of the TVA granulation process, very little granulation of mixed fertilizers was carried on in the United States, although granulation was common in some foreign countries.

The granulation processes that were in use involved imposing granulation as a separate additional step on whatever manufacturing process was being used for making pulverant fertilizers. The powdered fertilizers were granulated by addition of water in a rotating drum or pan, after which the granules were dried and screened. This method added appreciably to the cost of manufacture, and was not entirely satisfactory.

The TVA granulation process combines mixing, ammoniation, and granulation in one step. Emphasis was placed on devising formulations that would granulate readily at low moisture content, so that little or no drying would be required. Granulation at low moisture content was feasible at elevated temperature (200 -250 F.). The formulations were selected so that there would be sufficient heat of reaction to provide the desired temperature. The heat of reaction of superphosphates with ammonia was often insufficient to provide the desired temperature. Therefore, in some cases, sulfuric acid and additional ammonia were included in the formulation to increase the heat of reaction. In other cases, the desired temperature was obtained by using steam.

Emphasis was placed on maximum use of ammonia or ammoniating solutions since these are the cheapest and most concentrated nitrogen materials available to the manufacturer. Liberal use was made of the higher-analysis phosphate materials—concentrated superphosphate and phosphoric acid. Typical granular high-analysis products were 12-12-12, 15-15-15, 10-20-20 and 5-20-20. Formulations typical of those used successfully in the pilot plant are shown in Table 1.

TABLE 1.—Typical Formulations for the Production of High-Analysis Granualr Fertilizers.
(TVA Continuous Ammoniation-Granulation Pilot Plant)

Formulation, lb./ton product	12-12-12	15-15-15	10-20-20	5-20-20
Anhydrous ammonia	-----	----	-----	125
Ammoniating solution A (40.6% N)	499	-----	499	----
Ammoniating solution C (37% N)	-----	519	----	----
Ammonium sulfate (20.5% N)	195	537	----	----
Ordinary superphosphate (20% APA)	591	-----	----	355
Concentrated superphosphate (48% APA)	264	291	850	702
Phosphoric acid (78% H_3PO_4)	-----	289	----	----
Potassium chloride (60% K_2O)	400	500	667	667
Sulfuric acid (66° Bé)	155	-----	115	140

In many cases, granulation decreased the cost of the products because the saving in the cost of raw materials more than offset increased operating costs. The lower-cost raw materials could not be used successfully in nongranular fertilizers because of the poor physical properties of the products. Granulation also made it practical to produce higher-analysis products that would not have acceptable physical

properties unless granulated. The higher-analysis products brought about savings in bagging, storage, shipping, and on-the-farm handling as a result of their high concentration.

Some of the low-nitrogen, high-potash grades, such as 4-16-16 and 3-9-27, were difficult to granulate when all of the raw materials were of small particle size. It was found that granulation of these grades was greatly improved by using coarse potassium chloride. The coarse particles of potassium chloride served as nuclei around which the granules formed. This resulted in more uniform, efficient granule formation. The finished granules contained a core of potassium chloride and a hull of ammoniated superphosphate. The optimum size of potassium chloride for nucleation was about 6 to 16 mesh. Coarse superphosphate was equally effective for nucleation. In this case, the resulting granules contained a core of ammoniated superphosphate and a potash-rich hull.

Since heavy ammoniation of the superphosphates was characteristic of the granulation process, the water solubility of the phosphorus was low (20 to 30 percent) when ordinary superphosphate was the only source of phosphorus. However, concentrated superphosphate was used in most of the high-analysis products. Even heavy ammoniation of concentrated superphosphate did not decrease the water solubility of the phosphorus below 50 percent. The higher-analysis products that were made with concentrated superphosphate were more economical in most cases (8).

C. Granular Superphosphates Produced by a One-Step Process

Granular ordinary and concentrated superphosphates offer certain advantages over pulverant materials for direct application. In some areas of the country there is considerable farmer preference for granular over the nongranular materials. It also has been demonstrated that granular water-soluble fertilizers, such as superphosphates, may be more effective than pulverant materials in furnishing phosphorus to the crop, particularly on acid soils (13,33,35).

TVA has developed a process for granulation of superphosphates. Equipment such as TVA continuous ammoniators can be adapted to the process with relatively minor additions. The process should be useful to fertilizer manufacturers who already have continuous ammoniators and wish to diversify their production, as well as to producers of superphosphate who wish to produce a granular product.

1. *Concentrated Superphosphate.* Production of granular concentrated superphosphate was successfully carried out using the ammoniating drum (Figure 1) as a continuous acidulator. Phosphate rock (75 percent −200 mesh) and recycle from the product screens were fed into the acidulating drum. Phosphoric acid, either wet-process or furnace acid, and steam were fed under the bed of material in the drum. The steam aids in maintaining both temperature and moisture level required for granulation. The superphosphate granules thus produced had a porous structure which permitted ammonia absorption to about the same degree as does pulverant superphosphate. After 2 weeks' curing, conversion of P_2O_5 from rock usually was 93 percent.

2. *Other Superphosphates.* Ordinary superphosphate (20% P_2O_5) and one grade of enriched superphosphate (34% P_2O_5) were produced in the pilot plant by similar means. In production of granular ordinary superphosphate, 97 percent conversion of the P_2O_5 in the rock occurred after 2 weeks' curing.

3. *Phosphorus Availability to Plants.* The porous nature of the superphosphate granules produced in the pilot plant contrasts sharply with the more compact harder granules produced by other processes. A greenhouse study was made to compare availability of the pilot plant product with other granular superphosphates varying in hardness. The objective was to determine if this factor influenced availability to plants. It appeared possible that the rate of dissolution and penetrability to roots might be less with the hard than with softer granules.

Results of this experiment are shown in Table 2. Observed differences in hardness did not relate to responses in dry weight or phosphorus uptake despite marked effects of the applied phosphorus. Evidently the dissolution of water-soluble phosphorus and its distribution in the vicinity of the granule was unaffected by degree of hardness, for, as shown by Bouldin and Sample (1) such differences would be expected to influence relative availability. Neither does it appear that the dicalcium phosphate residues remaining at the pellet site differed in availability.

D. Superphosphate for Immediate Use in Ammoniation and Granulation Processes

The feasibility of an integrated process involving acidulation of the phosphate rock, ammoniation, introduction of other raw materials, and granulation in production of mixed fertilizers has been demonstrated (41). Ordinary superphosphate made by conventional methods requires from 2 to 6 weeks' curing to attain a satisfactory level of phosphorus conversion.

Table 2.—Yield Response and Uptake of Phosphorus by Millet from Concentrated Superphosphates Varying in Granule Hardness (DeMent and Terman, 1957). (Soil: Mountview Silt Loam, pH 6.6).

Concentrated superphosphate, −10+12 mesh (48% P_2O_5)	P applied, mg. per pot	Dry weight, g. per pot	P uptake, mg. per pot
None	0	0.7	0.5
Soft granules[1]	50	18.3	10.3
Granules of medium hardness[2]	50	19.8	10.4
Hard granules[3]	50	17.8	10.3
L.S.D. (5%)		2.0	1.5

[1]Pulverant super, granulated with steam and water.
[2]Produced by one-step process in continuous ammoniator used as an acidulator.
[3]Produced commercially by the Dorr process. Granules were dense and hard.

In the TVA process, 95% conversion was obtained in 1 hour when finely ground phosphate rock (90% −200 mesh) was acidulated with 60% sulfuric acid at an acidulation mole ratio of 1:1 (0.66 lb. H_2SO_4/lb. rock). The effect of size of phosphate rock on P_2O_5 conversion in 1 hour is shown in Figure 3.

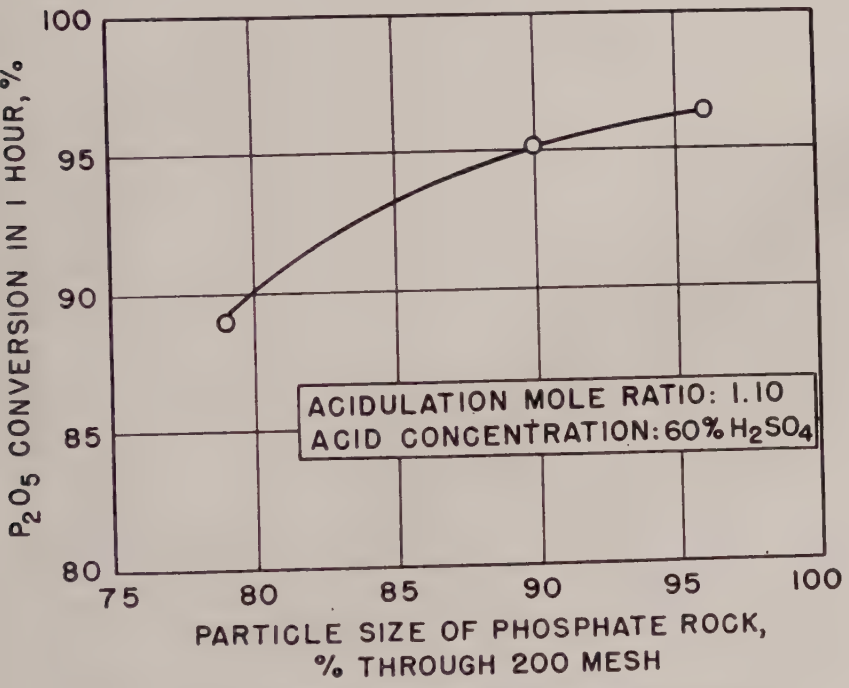

Figure 3.—Effect of particle size of rock on P_2O_5 conversion in 1 hour (41).

The effect of acidulation mole ratio on phosphorus conversion to "available" form in one hour is shown in Figure 4. Normally, an acidulation ratio of about 0.98 is used by industry. In pilot-plant tests of the "quick" process, ratios in the range of 1.1 to 1.5 were used. The increased amount of acid over that used in the production of conventional superphosphate served two functions. It aided in rapid conversion of P_2O_5 and served to fix ammonia and aid granulation when the superphosphate was used in the production of high-analysis fertilizers. The amount of excess acid was no greater than that used in the formulation of most grades of fertilizers. Therefore, in most cases, it did not increase the overall cost of materials.

In the pilot plant, acidulation was carried out in a TVA-type funnel mixer. The acidulate was discharged onto a continuous den of the Broadfield type (see Figure 5). After a denning time of about 50 minutes, the porous, friable superphosphate could be conveyed continuously to the ammoniator. Typical grades produced in granular form were 4-16-16, 6-12-12, and 10-10-10 (41).

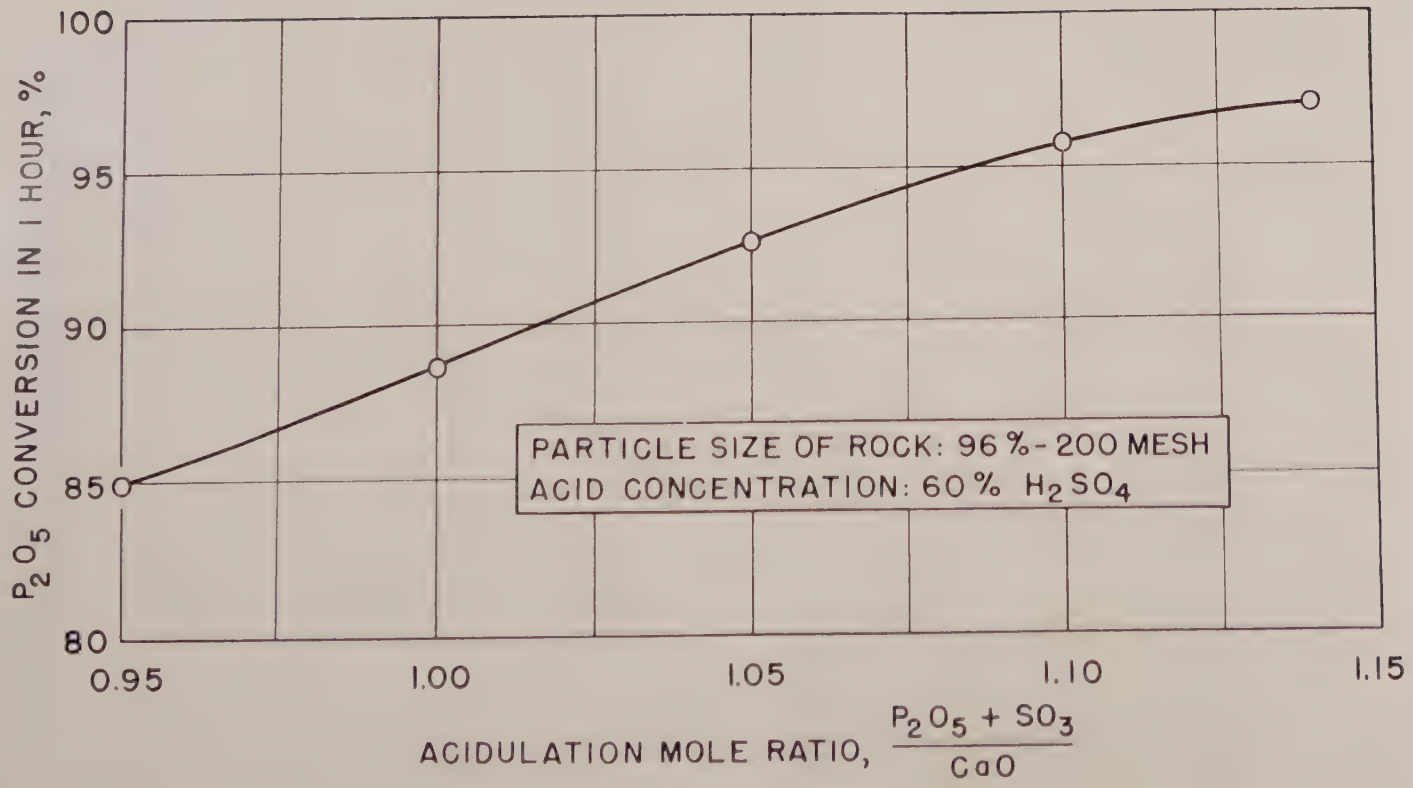

Figure 4.—Effect of acidulation ratio on P_2O_5 conversion in 1 hour (41).

Similar techniques may be applied in production of concentrated and enriched superphosphate for immediate use in ammoniation and granulation processes.

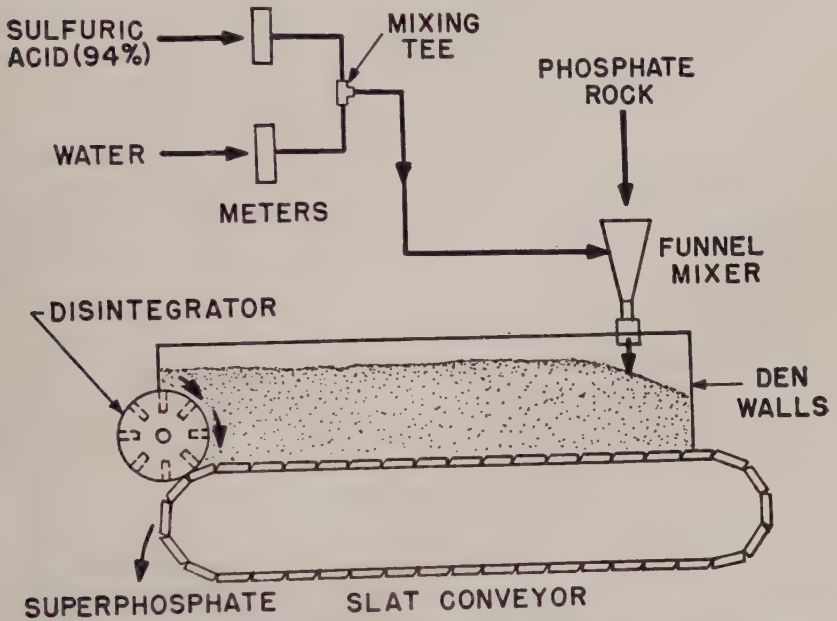

Figure 5.—Arrangement of pilot-plant funnel mixer and den in production of ordinary superphosphate for immediate use in ammoniation and granulation processes (41).

E. Granular Phosphorus-Potassium Fertilizers

1. *Production Using Phosphate Rock and Potassium Chloride (KCl).* Grades ranging from 0-14-14 to 0-26-26 have been produced in the pilot plant, using phosphate rock to supply all or part of the phosphorus. As in production of granular superphosphate, rock was acidulated with sulfuric or phosphoric acids in the continuous ammoniator. Other ingredients were KCl and, usually, cured superphosphate.

Production of no-nitrogen grades by this means possesses some advantages over the usual method of granulating KCl and superphosphate with steam. The plasticity of newly formed superphosphate facilitates granule formation. Also, stronger granules are obtained, and no additional heat for drying is necessary. Direct use of low-cost rock to furnish phosphorus is an attractive feature of the process.

2. *Implications of Superphosphate–KCl Combination to Phosphorus Availability.* Phosphorus availability may be enhanced by intimate association of superphosphate and KCl, as shown in recent studies by Bouldin and Sample (1). One reason for this effect is

that the presence of KCl results in a lesser residue of dicalcium phosphate at the pellet site. Moreover, higher availability of phosphorus exists in the soil-fertilizer reaction zone around the pellet than in the case of the superphosphate granule alone. The effect of KCl in the granule vs. KCl mixed separately in the soil upon availability of phosphorus from pelleted superphosphate is illustrated in Table 3.

TABLE 3.—Influence of Intimate Association of KCl and Concentrated Superphosphate (CSP) on Yields of Oat Forage and Phosphorus. [Bouldin and Sample (1)]

Pellet Components	Hartsells fine sandy loam		Mountview silt loam	
	Dry matter g./pot	P yield mg./pot	Dry matter g./pot	P yield mg./pot
None	2.2	2.5	2.2	1.9
CSP alone[1]	8.0	10.1	6.2	6.4
CSP + KCl[2]	8.4	11.3	7.0	8.7
L.S.D. (5%)	0.6	1.2	0.7	1.1

[1]N and K supplied by separate application.
[2]N and additional K by separate application.

F. Nitric Phosphates

Nitric acid, rather than sulfuric acid, may be used to react with phosphate rock to make its phosphorus content available. The products made by this method have been called nitric phosphates. Interest in production of nitric phosphates was stimulated by a shortage of sulfur and a rapid increase in capacity to produce nitric acid. TVA has developed several nitric phosphate processes through the pilot plant stage (38). The earlier of these processes and similar processes developed in Europe have not gained wide acceptance in this country probably because (a) the equipment required is considerably more expensive than for the usual fertilizer plant, (b) entirely new plants have to be built, since little use can be made of the usual type of plant, and (c) the processes are not adaptable to the manufacture of a large variety of grades, nor is the equipment adaptable to other processes (9). Three plants of this type are in commercial operation in this country.

Recently, however, TVA has demonstrated that nitric phosphate fertilizers can be made in equipment such as is used in some conventional fertilizer granulation plants with relatively minor changes and additions. The equipment would be versatile and a wide variety of grades of either nitric phosphate or conventional fertilizers could be produced. Moreover, the investment for an entirely new plant would be much less than that for a plant to produce nitric phosphates by the method first developed.

1. *Continuous Production in the Ammoniator-Granulator.* The TVA work on the new method for producing nitric phosphate fertilizers was carried out in the continuous ammoniation-granulation

pilot plant (10). Phosphate rock was extracted with nitric acid mixed with sulfuric or phosphoric acids, and the slurry was fed continuously to the ammoniator.

Typical grades made in the continuous ammoniator pilot plant included 12-12-12, 14-14-14, 10-15-20, and 10-20-15. In the 12-12-12 grade, sulfuric acid, ammonia and KCl were used. The 14-14-14 was formulated in different ways to demonstrate the versatility of the process. Phosphorus ingredients, in addition to phosphate rock, included phosphoric acid, concentrated superphosphate, or calcium metaphosphate. Addition of calcium metaphosphate in the extraction step favored its hydrolysis to the orthophosphate, thus permitting additional absorption of ammonia. Formulation of the 10-15-20 and 10-20-15 grades involved extraction of phosphate rock with nitric acid and addition of concentrated superphosphate and ammonia in the ammoniator. Citrate solubility of the nitric phosphates was about 96 to 99 percent of the total phosphorus, of which 20 to 30 percent was water soluble.

Estimates indicate that 12-12-12 and 14-14-14 nitric phosphates could be produced at less cost per unit of plant nutrients than corresponding conventional grades in locations where nitric acid is available at a reasonable price.

2. *Nitric Phosphates as Sources of Phosphorus to Crops.* Rogers, et al. (23) and Thorne, et al. (36) have summarized results from numerous field experiments comparing crop responses to the nitric phosphates and concentrated superphosphate or conventional mixed grades. On acid soils materials differed little for corn, cotton, and small grains, despite wide variation in water solubility of the fertilizer phosphorus. In other instances, particularly on small grains for forage, vegetable crops, and corn in the northern states, degree of phosphorus water solubility (in materials based on ammoniated ordinary superphosphate as well as in nitric phosphates) has been correlated with crop response (35). Often it appeared desirable to have one-third or more of the phosphorus in water-soluble form.

G. Ammonium Phosphate-Nitrates

1. *Continuous Ammoniation-Granulation Process.* Production of granular fertilizers from phosphoric acid and ammonia-ammonium nitrate solution also has been accomplished successfully in the pilot-plant ammoniator-granulator (25). Typical high-analysis grades included 17-17-17, 11-22-22, 8-16-32, 16-48-0, 28-14-0, and 30-10-0. The materials are fully water soluble.

Both wet-process and furnace-grade phosphoric acids have been used. KCl was used to supply potassium. To supply sulfur, if desired, ammonium sulfate, potassium sulfate, or sulfuric acid can be introduced. This, of course, adds to the versatility of the continuous ammoniator method.

When furnace acid was used, some grades were rather difficult to granulate. However, this difficulty was overcome by adding a small amount of finely ground iron ore or aluminum sulfate. Iron ore was very effective at a rate of 10 pounds per ton of product.

2. *Agronomic Implications.* Intimate association of the nitrogen and phosphorus components as in the case of ammonium phosphates occasionally has resulted in more efficient use of the phosphorus during early growth of plants (5, 14, 15). Nitrate nitrogen, on the other hand, when banded with the phosphorus fertilizer has been observed to depress early uptake of phosphorus (14). The significance of these results relative to effectiveness of ammonium phosphate-nitrates varying widely in proportion of nitrate to ammoniacal nitrogen is not known. Perhaps the differences would be of little practical significance under field conditions.

The possibility of sidedressing 30-10-0 for corn and cotton or topdressing for small grains and grasses to supply additional phosphorus as well as nitrogen is of interest. Delayed application of phosphorus in such instances is not commonly recommended for there is little experimental evidence as to the desirability of such a practice. Studies now in progress under cooperative TVA-state contracts, comparing planting and delayed application, are expected to clarify the problem. Preliminary indications are that topdressing after crop emergence is about as effective as broadcasting prior to seeding but not as effective as drilling with the seed.

II. FERTILIZER FROM LEACHED-ZONE ORE

A layer of "leached-zone" material, containing phosphorus principally as aluminum phosphates, overlies the phosphate rock matrix in Florida deposits. This leached-zone ore, normally discarded in phosphate mining operations, constitutes an important phosphate reserve, and about 1,400,000 tons P_2O_5 of this potential reserve are moved or discarded annually. TVA is interested in developing economic methods of producing fertilizer from it. Another objective of TVA's initial work along this line also was to develop an integrated process for recovering uranium from the leached-zone ore as well as using the ore for fertilizer production.

The leached-zone ores are variable in composition, as indicated below:

Percent P_2O_5	10-15
Percent Al_2O_3	8-16
Percent SiO_2	52-66
Percent CaO	2-12

A. Preparation and Properties

The pilot plant production of fertilizer from leached zone ore has been reported by Hignett, et al. (12). The ore was calcined at 2000° F. to 2100° F. and phosphorus was extracted with nitric and sulfuric acids. The extraction slurry was filtered and the filtrate then concentrated by evaporation. The concentrated filtrate was ammoniated and granulated successfully in the continuous ammoniation-granulation pilot plant, with or without the addition of KCl to produce grades such as 15-15-15, 20-20-0, and 11-22-11. The dried products had very satisfactory physical properties.

Water solubility of the phosphorus in the leached zone fertilizers may be varied from about 5 to 30 percent, depending on the relative proportions of nitric and sulfuric acids used. Near maximum solubility of phosphorus was achieved with a 1:1 weight ratio of these acids. The use of sulfuric acid is beneficial, since it precipitates calcium sulfate, thus improving both phosphorous solubility and filterability of the slurry.

The analyses of certain fertilizers produced from leached-zone ores are compared with some of the nitric phosphates derived from conventional Florida rock phosphate in Table 4, adapted from the paper by DeMent and Seatz (2). Phosphorus in the fertilizer is present largely as amorphous aluminum phosphate, with small quantities of ammonium and calcium phosphates.

TABLE 4—Chemical Composition of Phosphorus Fertilizers Produced from Leached-Zone and from Conventional Florida Ore

Nominal grade	P_2O_5		Al_2O_3 %	CaO %
	Citrate soluble	Water soluble, % of total		
15-15-15 (LZ)	15.8	27.7	8.0	1.7
15-15-15 (LZ)	14.8	4.0	5.2	0.5
15-29-0 (LZ)	29.0	27.1	11.4	5.7
12-12-12 NP III	11.8	15.6	----	17.3
12-12-12 NP IV	12.5	10.4	----	17.8

B. Source of Phosphorus for Plants

The fertilizers produced from leached-zone ores have been compared with nitric phosphates and concentrated superphosphate in a number of field and greenhouse experiments (2, 29). Based on field studies, DeMent and Seatz (2) reported that the leached-zone fertilizers were as effective as nitric phosphates or conventional mixtures having approximately the same degree of phosphorus water solubility. More recent unpublished data obtained in Michigan, Kentucky, Virginia, and Tennessee are in general agreement with these findings.

III. SUPERPHOSPHORIC ACID FOR USE IN FERTILIZER PRODUCTION

A. Production and Properties of Superphosphoric Acid

The phosphoric acid available to industry for use in fertilizer formulations, called phosphatic fertilizer solution, contains about 55 percent P_2O_5 (75% H_3PO_4). On a trial basis, TVA has produced an acid containing 76 percent P_2O_5 (equivalent to 105 percent H_3PO_4). This so-called "superphosphoric" acid is made in the full-scale TVA plant with some modification of the method used in producing phosphatic fertilizer solution (31).

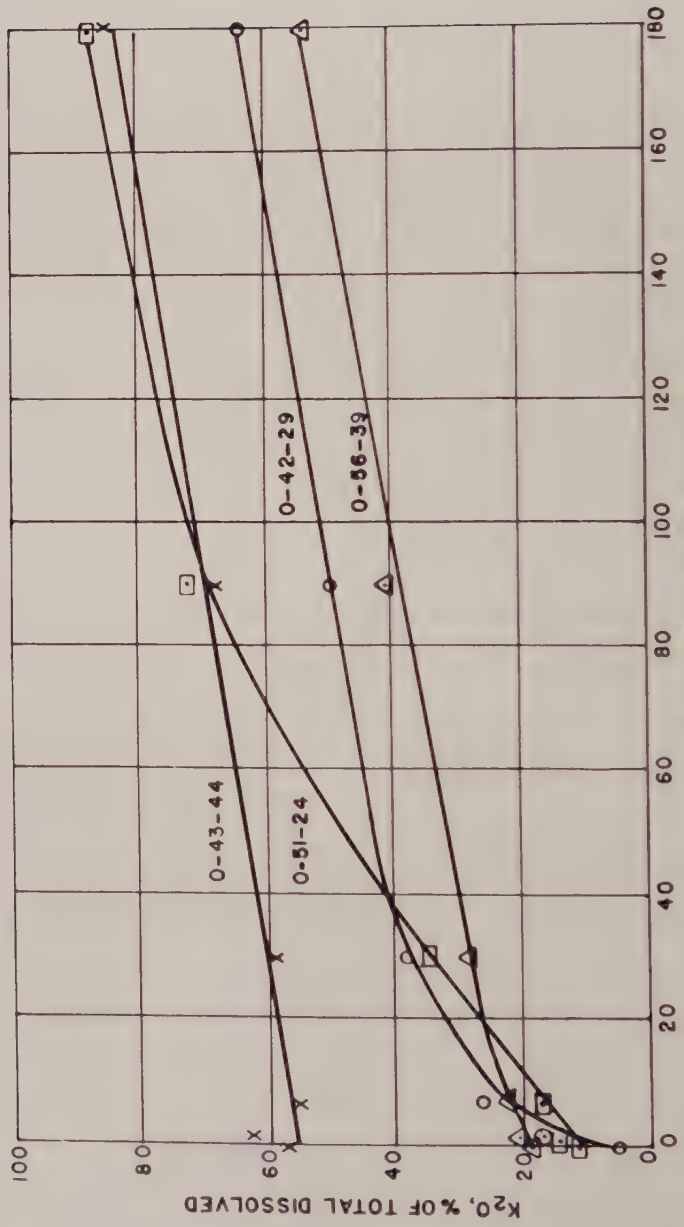

Figure 6.—Solubility of four fused potassium phosphates in water in relation to time.

The superphosphoric acid is intermediate in composition between 100 percent H_3PO_4 (72.4% P_2O_5) and pyrophosphoric acid, (79.8% P_2O_5), both of which are solids at room temperature. The superphosphoric acid, however, does not crystallize at ordinary temperatures. About one-half of the phosphorus is present as pyrophosphate.

It is less corrosive than ordinary acid and contains only about half as much water. Striplin, et al. (31) have described its properties in detail.

The high concentration and high density (16 lb./gal.) of superphosphoric acid are advantageous in reducing storage requirements. For example, with concentrated acid, 70 percent more phosphorus can be stored per unit volume than with ordinary phosphoric acid. Savings in transportation cost per unit of phosphorus also can be realized. At the same rate per ton, freight saving is about 28 percent per unit of phosphorus.

B. Use in Production of High-Analysis Solid Fertilizers

1. *Superphosphate (54-56% P_2O_5).* Superphosphoric acid is now being used in producing a more concentrated superphosphate than can be made from treatment of phosphate rock with ordinary phosphoric acid. The product contains from 54 to 56 percent P_2O_5, most of which is present as anhydrous monocalcium phosphate, $Ca(H_2PO_4)_2$. Concentrated superphosphate (45-48% P_2O_5) on the other hand, consists largely of $Ca(H_2PO_4)_2.H_2O$. The presence of one mole of water of crystallization accounts for the difference in analysis.

2. *Granular Mixed Fertilizers From 54 - 56% Superphosphate.* The high-analysis superphosphate produced from acidulation of rock phosphate with superphosphoric acid can be used in the same manner as other superphosphates in the production of granular mixed fertilizers. Recently, 6-24-24 and 12-24-12 were made in the pilot plant, using this source of phosphorus together with ammonia, nitrogen solution, and KCl. These grades are higher in analysis than can be produced from the lower grade concentrated superphosphate (46 to 48 percent P_2O_5). Moreover, cost estimates indicate considerable economic advantage in their production as compared with 5-20-20 and 11-22-11.

3. *Use of Superphosphoric Acid in Production of Granular Fertilizers.* Since heat is produced upon dilution as well as upon ammoniation of the superphosphoric acid, a higher temperature per unit of phosphorus is reached in the ammoniator than with ordinary phosphoric acid. This was advantageous, for example, in producing a 5-20-20 grade. Granulation occurred at a lower moisture input than with formulations from ordinary phosphoric acid or concentrated superphosphate. Consequently, the moisture content of the product was lower. Granulation efficiency also was higher with the superphosphoric acid than with the ordinary phosphoric acid. These and other observations comparing the ordinary and superphosphoric acids in production of 5-20-20 are given in Table 5 (from unpublished data). In other tests in the pilot plant and in a commercial plant, other grades have been made, including 5-20-10, 7-28-28, and 17-17-17.

C. Liquid Fertilizers from Superphosphoric Acid

1. *Production and Properties.* When the superphosphoric acid is ammoniated under properly controlled conditions, ammonium pyrophosphates are formed. This compound is more soluble than the

TABLE 5—Production of Granular 5-20-20 Fertilizer Using Ordinary (56% P_2O_5) and Super (76% P_2O_5) Phosphoric Acids as the Major Sources of Phosphorus.

	Superphosphoric acid (76% P_2O_5)	Ordinary Phosphoric acid (56% P_2O_5)
Formulation, lb./ton of product		
Anhydrous ammonia	125	125
Ordinary superphosphate	902	902
Phosphoric acid	294[1]	396[2]
Potassium chloride	667	667
Total	1988	2090
Water	118	232
Recycle	600	500
Moisture, %		
Input to ammoniator	6.7	14.0
Screened product	2.8	6.9
Temperature (°F.) ammoniator product	225	177
Screen analysis, cooler product		
Oversize (+6 mesh)	21.8	29.7
Onsize (−6+28 mesh)	72.2	49.1
Undersize (−28 mesh)	6.0	21.2

[1]105% H_3PO_4
[2]78% H_3PO_4

corresponding ammonium orthophosphates. Thus, higher analysis liquid fertilizers may be made from the acid containing about 50 percent pyrophosphate without danger of salting out at low temperature (32).

Grades of 11-33-0 and 11-36-0 were produced by ammoniation. By addition of urea or urea-ammonium nitrate solution and potassium chloride, grades such as 10-10-10, 9-18-9, 7-21-7, and 5-15-10 were made that did not salt out at 30° F. These grades are higher than can be made from ordinary acid.

Using still more concentrated phosphoric acid (78.3% P_2O_5) and ammonia, a 13-45-0 grade was produced in the pilot plant. By addition of urea or aqua ammonia and water, this grade was adjusted to 12-36-0. These solutions did not crystallize at 4° F., the lowest temperature tried thus far. Although the 78 percent P_2O_5 acid may be difficult to ship owing to crystallization, it may be feasible to ammoniate it at the point of production and ship the base solution for use in the production of liquid fertilizers.

The production of high-analysis liquid fertilizers from superphosphoric acid has twice been demonstrated in commercial-scale equipment outside of TVA.

2. *Addition of Trace Elements to Liquids.* One of the disadvantages of liquid fertilizers prepared from ordinary (orthophosphoric) acid is the inability to hold significant quantities of most trace element salts in solution. Sulfates of manganese, copper, iron, and zinc, when added as a mixture, are practically insoluble in the neutral liquid

mixes (26). Boron in compounds now supplied by the borax industry, however, has adequate solubility. Dissolving as much as 5 percent (borax equivalent) would be feasible.

Slack (26) reports that a combination of the trace element salts indicated above, when dissolved in superphosphoric acid, was quite soluble upon ammoniation, but precipitated on long standing. The precipitate stayed in suspension quite well, however, and probably would not present an application problem.

Iron was an exception in that a stable solution was formed with as much as 7% by weight of $Fe_2(SO_4)_3XH_2O$ (see Table 6). The ferrous sulfate, however, was much less soluble. Evidently, a chelation of ferric iron occurred. It has been noted (unpublished data, TVA) that addition of 10 parts phosphorus as superphosphoric acid to 90 parts as ordinary wet-process phosphoric acid prevents precipitation of the iron and aluminum impurities present in the wet process acid upon ammoniation.

In bench-scale tests, considerably more of the trace element salts dissolved in ammoniated superphosphoric acid (11-35-0) than in ammoniated ordinary acid (8-24-0) (Table 6). Little manganese dissolved in either solution. Borax dissolved equally well in both solutions.

TABLE 6.—Solubility of Trace Elements in Liquid Fertilizers Produced by Ammoniation of Superphosphoric and Ordinary Acids. (Tennessee Valley Authority, unpublished)

Trace element salt added	Maximum amount of salts in solution after storage at room temperature for 72 hours (% by weight)	
	11-35-0	8-24-0
$Fe_2(SO_4)_3.XH_2O$	7.0	Trace
$FeSO_4.7H_2O$	0.5	<0.25
$ZnSO_4.7H_2O$	9.0	0.25
$MnSO_4.H_2O$	<0.25	<0.25
$CuSO_4.5H_2O$	6.0	0.5
$Na_2B_4O_{10}.10H_2O$	8.0	8.0

3. *Liquid vs. Solid Fertilizer Use.* Slack (26) estimated that in 1955 there were 72 producers in the United States making and distributing liquid fertilizers containing two or more plant nutrients; in 1957 there were about 166 producers. Despite this spectacular growth, tonnages are still relatively small for the country as a whole. Cost and availability of suitable raw materials, particularly furnace-grade phosphoric acid, have controlled growth rate of this segment of the fertilizer industry. Present centers of the industry are the Midwestern states and California.

In general, comparisons of crop response to conventional liquid fertilizers made from ordinary furnace-grade acid and to water-soluble solid materials have revealed no differences. Concentrated superphosphate clearly was equal to liquids as a source of phosphorus in recently reported experiments in Iowa (17).

The more concentrated liquid NP or NPK liquids produced from superphosphoric acid contain about one-half of the phosphorus as ammonium pyrophosphate. In view of this unique chemical composition, it was of interest, therefore, to compare this material with conventional liquids as a source of phosphorus for crops.

Results shown in Table 7 were obtained in a greenhouse experiment at Wilson Dam (unpublished data, TVA). There were no significant differences between the two liquid formulations or between solid 21-53-0 and liquids. This was true whether localized or mixed placement was used. It is clear that the spot placement involving less volume of soil-fertilizer contact was superior to mixed placement. This and other evidence indicates that, using the same placement, similar results can be expected from liquids and solids. To be comparable, of course, solids also must be water-soluble. A number of field experiments now are being conducted in various states comparing conventional liquids, solids, and liquids prepared from the concentrated acid. Included also are liquids prepared by dissolving NH_3 P_2O_5 reaction products (30) discussed in a later section.

TABLE 7.—Comparison of Solid and Dissolved Diammonium Phosphate with a Solution of Ammoniated Superphosphoric Acid (11-36-0) as a Source of Phosphorus for Millet. (Hartsells Fine Sandy Loam, pH 5.3)

Fertilizer material (applied at 40 mg. P_2O_5/pot)	Yield of[1] dry matter (g./pot)		Yield of[2] phosphorus (mg./pot)	
	Spot-placed	Mixed w/soil	Spot-placed	Mixed w/soil
Solid DP[3] (21-53-0)	8.0	5.5	6.1	5.0
Solution of DP (8-20-0)	8.7	5.6	6.7	4.8
Solution-ASPA[4] (11-36-0)	8.4	6.2	6.7	5.3

[1]Yield without P=1.0 g.; LSD (5%) for treatment=0.8 g.
[2]P uptake with no P=1.0 mg.; LSD (5%) for treatment=0.7 mg.
[3]Diammonium phosphate.
[4]Ammoniated superphosphoric acid.

It appears that economics of manufacture and distribution and relative convenience and cost to farmers of liquids and solids will determine future trends in the liquid fertilizer industry. These aspects of the problem have been discussed by Stanfield (27), Robertson, et al., (22), and by Slack (26).

IV. THE METAPHOSPHATES

Interest in the metaphosphates has continued owing to the high phosphorus content of such products. The property of gradual dissolution and hydrolysis of metaphosphates in soils has caused some speculation that they might be superior to water-soluble compounds in supplying the phosphorus needs of crops. Potassium meta phosphate is of interest as a source of slowly available potassium as well, and will be considered in this connection.

A. Calcium Metaphosphate

1. *Production and Properties.* The development of a plant-scale fusion process for producing calcium metaphosphate (60-65% P_2O_5) has been discussed by Walthall (38). Elemental phosphorus and powdered phosphate rock are burned at somewhat above 1000° C. in a combustion chamber. The P_2O_5 and fluorapatite react to form calcium metaphosphate, $Ca(PO_3)_2$, and hydrogen fluoride, HF. Typically, the final product contains about 5% SiO_2, less than 5% Fe_2O_3+ Al_2O_3, 62-64% total P_2O_5, about 26% CaO, and about 0.2% F.

Water solubility of the phosphorus usually is quite low (about 2%) while almost all is soluble in neutral ammonium citrate solution (−35 mesh product with continuous agitation during extraction).

Walthall (38) states that, typically, the proportions of material passing 20-, 100-, and 200-mesh sieves are 86, 23, and 13%, respectively. Before bagging, 2 to 4% of limestone is mixed with the product to prevent caking. Probably the limestone reacts with monocalcium phosphate, produced by hydrolysis on particle surfaces, to form dicalcium phosphate. For bulk handling, a small amount of petroleum product is added to minimize dustiness.

In recent TVA tests, calcium metaphosphate was granulated successfully by preheating and treating it with water in a rotary drum. The product had excellent physical properties for direct application and dry blending in mixed goods. A certain amount of hydrolysis took place during the treatment, and the resulting granular product had about 10 percent of the total phosphorus in water-soluble form.

2. *Use of CMP in Production of Granular Mixed Fertilizers.* A limitation to the use of CMP in formulation of mixed fertilizers is its inability to fix ammonia. Upon hydrolysis, however, monocalcium phosphate and other compounds form that will react with ammonia.

Recent pilot-plant tests have indicated the feasibility of continuously hydrolyzing CMP with dilute acid and ammoniating and adding KCl to produce grades such as 12-12-12, 8-16-16, and 6-24-24. The CMP, hydrolyzed with dilute sulfuric or phosphoric acid was fed as a slurry into the ammoniator (19).

Preliminary work on hydrolysis and ammoniation of CMP at elevated temperature and pressure, in the presence of ammoniating solutions, also has given promising results. Petrographic studies have shown that the resulting product may contain 30 to 50% of its nitrogen in the form of calcium-ammonium pyrophosphate, $Ca(NH_4)_2P_2O_7$. This compound is relatively water-insoluble. The availability to plants of the water-insoluble nitrogen-phosphorus compound is currently being studied.

3. *Source of Phosphorus for Crops.* For a number of years, the output of the demonstration-scale plant at Muscle Shoals has been utilized in research by agricultural experiment stations, in farm demonstrations, and, more recently, in formulation of high analysis mixtures.

Results of a large number of field experiments comparing CMP and other phosphorus sources have been published during the past several years. On a wide range of acid to neutral soils, crop responses

to CMP and concentrated superphosphate generally were equal (23, 34, 37). On alkaline soils, where water solubility of phosphorus is relatively more important than on acid soils, crop response to superphosphate occasionally has been superior (24, 34, 37). On the other hand, residual effects following the year of application have been equal for CMP and superphosphate.

In some experiments (37) coarse (−10 mesh) CMP has given lower crop response than finely ground (−40 mesh) CMP during the year of application. Granulated CMP, however, was as effective as finer size CMP (−35 mesh), according to preliminary greenhouse experiments conducted at Wilson Dam (unpublished data). Further studies are planned to compare granular *vs.* pulverant CMP for crops. Interest in this problem arises because the granular product possesses more desirable physical characteristics for direct application than does the pulverant product.

B. Ammonium Metaphosphate Fertilizer

Laboratory studies by Driskell (4) demonstrated the feasibility of reacting ammonia and dry P_2O_5 vapor to form a high-analysis product. This led to the development of a process for making 17-73-0 solid on a pilot-plant scale. Later, a method of preparing 12-36-0 liquid from the reaction products was devised. At the moment, work on this project has been suspended, pending further study of the economics of large-scale production.

1. *Preparation and Properties.* A pilot plant was developed for producing 17-73-0 from reaction of dry P_2O_5 vapor and ammonia at elevated temperatures (600-1000° C.). Most of the reaction product was ammonium metaphosphate, NH_4PO_3. The remainder probably consisted of phosphoronitridic acid, $(OH)_2PN$, and the ammonium salt, PNO_2HNH_4, which contained all or part of the nitrogen in non-ammoniacal form.

Typical products contained 80 to 86% ammonium metaphosphate. About 20 to 30% of the nitrogen and phosphorus was slowly soluble in water. Potash could be introduced during an intermediate step in the process. Detailed steps in preparation and properties of the materials were reported by Stinson, et al., (30).

2. *Use in Liquid Fertilizers.* When the dry P_2O_5 vapor was reacted with ammonia in the reaction chamber, a white "smoke" formed; this material was collected in an electrostatic precipitator and was treated with steam to obtain a solid fertilizer product having satisfactory physical properties. In other tests, the initial reaction products were dissolved directly in water to give high-analysis liquid fertilizers of approximately the same grades as those produced from ammoniation of superphosphoric acid (32). Producing a liquid fertilizer permitted bypassing the costly steps of precipitation, steam treatment (hydrolysis), drying, crushing, and sizing, which were necessary in the preparation of a solid fertilizer.

The dissolved reaction product of 12-36-0 analysis does not crystallize at 32° F. Trace elements are more soluble in this liquid prepara-

tion than in 12-36-0 from superphosphoric acid or 8-24-0 from ordinary phosphoric acid.

3. *Solid and Liquid Ammonium Metaphosphate Fertilizers as Nutrient Sources for Crops.* Initial greenhouse studies indicated that the solid NH_3-P_2O_5 reaction products generally were as effective as calcium metaphosphate or concentrated superphosphate, supplemented with ammonium sulfate, in supplying nitrogen and phosphorus for plants (30). A number of field trials conducted in various states over a 3-year period also have shown ammonium metaphosphate fertilizer to be as effective as standard fertilizers (unpublished data). Results thus far obtained suggest, therefore, that the small proportion of slowly soluble nitrogen and phosphorus present in this fertilizer neither enhances nor reduces its effectiveness.

Limited comparisons in greenhouse and field of liquid 12-36-0 with liquids prepared from ordinary and superphosphoric acid have revealed no consistent differences among materials.

V. SLOWLY SOLUBLE POTASSIUM FERTILIZERS

Soils possessing low exchange capacities (sands and loamy sands, for example) have a low capacity for retaining potassium, and in areas of high rainfall, appreciable losses occur by leaching. It is uneconomical to improve retention of soluble potassium fertilizers substantially by increasing the cation exchange capacity of the soil. Under such circumstances, a slowly soluble potassium compound would appear to offer advantages over completely soluble sources such as KCl and K_2SO_4.

Efforts are being made by TVA to develop a potassium phosphate fertilizer containing a high proportion of slowly soluble potassium. The most promising of the products being studied are potassium metaphosphate, KPO_3, and a compound approaching the composition of potassium-calcium pyrophosphate, $K_2CaP_2O_7$.

A. Pilot Plant Products

A pilot plant was constructed for producing fused potassium phosphates. Preliminary runs have been directed toward making materials which possess low potassium solubility, high phosphorus availability (citrate solubility), and low chloride content.

Walthall (38) has described a TVA pilot plant process for making potassium metaphosphate by high-temperature reaction of phosphorus, air, and KCl (1000° to 1050° C.). Products varied from 55 to 58 percent P_2O_5, 35 to 38 percent K_2O, and 1 to 4 percent chlorine. A pilot plant of modified design has been used more recently in production of both potassium metaphosphate and the potassium-calcium pyrophosphate.

Pure KPO_3 has the analysis 0-60-40. In crystalline form, it is slightly water soluble. Presence of as little as 2 to 3 percent Al_2O_3 or Fe_2O_3 impurities, however, results in a glassy or vitreous product which dissolves fairly readily in water. Rate of cooling of the melt also affects crystallinity and solubility.

The potassium-calcium pyrophosphate materials are produced through fusion of finely ground phosphate rock, KCl, and P_2O_5. Pure $K_2CaP_2O_7$ has the composition 0-49-32. Pilot plant products have ranged in analysis from about 0-40-27 to 0-50-25. Rapid quenching of the melt favors low potassium solubility and high citrate solubility of the phosphorus, while slow cooling increases citrate-insoluble phosphorus and water-soluble potassium.

The water solubility of some fused potassium phosphates (−35 mesh) in relation to reaction time is shown in Figure 6. The materials have been characterized in TVA's petrographic laboratory as follows:

Material	*Characteristics*
0-43-44	Contains crystalline KPO_3 and KCl
0-51-24	Major phase is vitreous glass with some occluded KPO_3 crystallites
0-42-29	Crystalline $K_2CaP_2O_7$ is an abundant phase
0-56-39	Coarse, blocky crystals of KPO_3 with minor amount of KPO_3 glass.

Except for the 0-43-44 containing appreciable quantity of KCl, initial solubilities in water (1-hour reaction time, corresponding to zero day on the graph) were low, ranging from 3.6 to about 20 percent of the total potassium. Event after 20 days, solubilities were of the order of 30 percent, and solution continued at a slow rate up to 180 days.

A major problem encountered in production of fused potassium phosphates is economical disposal of the HCl by-product. Its use for acidulation of rock phosphate is under investigation.

B. Availability of Fused Potassium Phosphates to Plants

Laboratory preparations of fused potassium phosphates varying in water solubility of the potassium were studied in greenhouse pot tests. Materials included and the percentages of the total potassium in water-soluble form were: Crystalline KPO_3 and $K_2CaP_2O_7$, less than 4 percent; $K_2CaP_2O_7$-like materials, 4.4 to 28.1 percent; and potassium metaphosphate preparations containing varying amounts of Al_2O_3 or Fe_2O_3, 6.5 to 100 percent. These were compared with KCl.

Yields and potassium uptake for 3 successive corn crops from Ruston sandy loam soil revealed no significant differences among potassium sources, notwithstanding the wide range in water solubility. These results obtained in successive cropping periods of 7, 6, and 7 weeks, respectively, indicated that dissolution of the materials (−35 mesh) occurred quite rapidly in the soils (3). Likewise, in measurements of short-term (1-week) uptake (28) of potassium by millet, no differences among sources were found with the −35 mesh materials. On the other hand, uptake during the first week of soil-fertilizer contact from −6+9 mesh materials was clearly proportional to percent of the total potassium present in water-soluble form (Figure 7). When

fertilizer-soil mixtures were incubated for two weeks prior to the introduction of actively growing plant roots, however, even the −6+9 mesh particles apparently had largely dissolved, for the effect of degree of water solubility on potassium uptake was small except with the least soluble material.

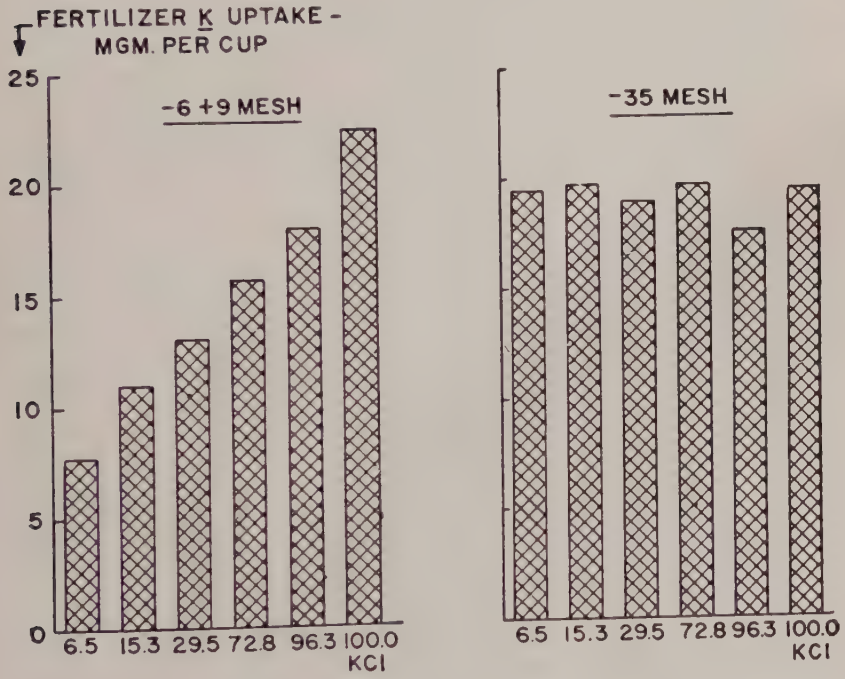

Figure 7.—Effect of water solubility and granule size of fused potassium phosphates and KCl on potassium uptake by millet during a 1-week period of growth.

With −6+9 mesh materials, it was shown that leaching losses were less from the fused potassium phosphates than from KCl. This difference was less pronounced after a 2-week soil-fertilizer incubation than when leaching occurred immediately after mixing soil and fertilizer. The importance of particle size in relation to leachability and availability of slowly soluble fused potassium phosphates has not been adequately evaluated. Studies of greater duration than one year are needed under field conditions. Cooperative studies are now underway in Alabama, Connecticut, Florida, Michigan, and North Carolina, which should throw light on the comparative residual effects of KCl and TVA pilot-plant materials.

Under circumstances where low chloride content of fertilizers is desirable and where high salt concentrations may be detrimental, the materials also are of interest. These problems are currently being studied in New York and Alabama.

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Suggested Ratios, Grades And Amounts Of Fertilizer For Use In Production Of Field Crops In Florida

J. R. Henderson*

In February of 1943, under provisions of Food Production Order No. 5 of the United States Department of Agriculture, the Florida Agricultural Experiment Stations compiled what is believed to be the first list of grades and amounts of fertilizer recommended for use on field crops in Florida. Recommended grades were those in common use at that time and recommended rates of application of the various grades for each crop were maximums. A total of 18 grades of mixed fertilizer were listed. Of these, 12 contained nitrogen, phosphorus and potassium, 5 contained phosphorus and potassium only and one contained nitrogen and potassium only, with average nutrient contents of 18.2, 23.8 and 29 percent, respectively. Mineral and organic soils were distinguished but differences among the mineral soils and use of minor elements were not considered in these recommendations.

TABLE 1.—Suggested Amounts of Nitrogen, Phosphorus and Potash for Field Crops in Florida when Results of Soil Tests are not Available[1]

Mineral Soils[2]	Sandy Loam[3] $N\text{-}P_2O_5\text{-}K_2O$	Loamy Sand[3] $N\text{-}P_2O_5\text{-}K_2O$	Sand $N\text{-}P_2O_5\text{-}K_2O$
Perennial grasses	96-48-48	96-36-48	96-24-48
Annual grasses	96-64-64	96-48-64	96-32-48
Cotton	64-64-64	64-48-64	64-32-64
Flue-cured tobacco	48-120-144	48-96-144	48-72-144
Clovers	0-70-70, or 0-72-108	0-54-81, or 0-55-110	0-44-88, or 0-45-135
Other legumes	0-56-56, or 0-54-81	0-42-63, or 0-44-88	0-33-66, or 0-36-108
Organic Soils	*Virgin soils*	*Next 3 yrs.*	*Subs. years*
All crops	0-48-144, or 0-50-100	0-60-90, or 0-60-60	0-72-48, or 0-70-35

[1]Amounts suggested are for good soil moisture conditions. For fair moisture conditions, amounts should be reduced by one-fourth to one-third and for poor moisture conditions amounts should be reduced by one-third to one-half.

[2]Suggestions for amounts on mineral soils that are not naturally phosphatic (see footnote 3), are based on the assumption that opportunity for build up of soil phosphorus has been provided by annual applications of mixed fertilizers containing phosphorus over a period of several years or through preplanting applications of phosphatic materials to virgin soils.

[3]Naturally phosphatic sandy loams and loamy sands of central and northern Florida (Hague, Zuber, Fellowship, Blichton, Gainesville, Arredondo and Ft. Meade series) should be treated as sands.

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TABLE 2.—Suggested Grades and Amounts of Fertilizer for Field Crops in Florida when Results of Soil Tests are not Available[1, 2]

Mineral Soils								
Perennial grasses	Sandy loam	9-9-9 (533)	+	N (48)	or	10-10-5 (480)	+	20-0-10 (240)
	Loamy sand	10-7½-10 (480)[3]	+	N (48)	or	12-9-6 (400)	+	20-0-10 (240)
	Sand	10-5-10 (480)	+	N (48)	or	12-6-6 (400)	+	20-0-10 (240)
Annual grasses	Sandy loam	5-10-10 (640)	+	N (64)	or	4-16-8 (400)	+	20-0-8 (400)
	Loamy sand	6-9-12 (533)	+	N (64)	or	4-12-8 (400)	+	20-0-8 (400)
	Sand	7-7-14 (457)	+	N (64)	or	5-10-10 (320)	+	20-0-8 (400)
Cotton	Sandy loam	5-10-10 (640)	+	N (32)	or	4-16-8 (400)	+	18-0-12 (267)
	Loamy sand	6-9-12 (533)	+	N (32)	or	4-12-8 (400)	+	18-0-12 (267)
	Sand	7-7-14 (457)	+	N (32)	or	5-10-10 (320)	+	18-0-12 (267)
Flue-cured tobacco[4]	Sandy loam	4-10-12 (1200)			or	3-15-3 (800)	+	5-0-25 (480)
	Loamy sand	4-8-12 (1200)			or	4-16-4 (600)	+	5-0-25 (480)
	Sand	4-6-12 (1200)			or	4-12-4 (600)	+	5-0-25 (480)
Clovers	Sandy loam	0-14-14 (500)			or	0-12-18 (600)		
	Loamy sand	0-12-18 (450)			or	0-11-22 (500)		
	Sand	0-11-22 (400)			or	0-9-27 (500)		
Other legumes	Sandy loam	0-14-14 (400)			or	0-12-18 (450)		
	Loamy sand	0-12-18 (350)			or	0-11-22 (400)		
	Sand	0-11-22 (300)			or	0-9-27 (400)		
Organic soils								
All Crops[5]	Virgin soil	0-8-24 (600)			or	0-10-20 (500)		
	Next 3 yrs.	0-10-15 (600)			or	0-12-12 (500)		
	Subs. years	0-12-8 (600)			or	0-14-7 (500)		

[1]See footnotes 1 and 2 and 3, Table 1.

[2]The grades listed for crops, except flue-cured tobacco, on mineral soils are not intended to contain minor elements nor natural organic sources of nitrogen. See Table 5 for grades containing minor elements, natural organics or a combination of the minor elements and natural organics that may be substituted.

The alternates suggested for non-legumes on mineral soils provide for supplying part of the potash from complete mixtures and part from nitrogen-potash mixtures.

[3]The current Florida Fertilizer Law prohibits the registration of 10-7½-10 as such.

[4]All grades for flue-cured tobacco should contain a minimum of 25 percent of the nitrogen in nitrate form, one-fourth as much soluble magnesium (MgO) as potash, and not more than one-fourth as much chlorine as potash.

[5]Grades suggested for use on organic soils should contain the necessary minor elements in the proper amounts.

TABLE 3.—Suggested Amounts of Nitrogen, Phosphorus and Potash for Field Crops in Florida when Results of Soil Tests are Available[1]

	Phosphorus Level of Soil	Potash Level of Soil		
		Low	Medium	High
		$N\text{-}P_2O_5\text{-}K_2O$	$N\text{-}P_2O_5\text{-}K_2O$	$N\text{-}P_2O_5\text{-}K_2O$
Mineral Soils				
Perennial grasses	Low	96-72-72	96-72-48	96-72-24
	Medium	96-48-72	96-48-49	96-48-24
	High	96-24-72	96-24-48	96-24-24
Annual grasses	Low	96-72-72	96-72-48	96-72-24
	Medium	96-48-72	96-48-48	96-48-24
	High	96-24-72	96-24-48	96-24-24
Cotton	Low	72-72-72	72 72-48	72-72-24
	Medium	72-48 72	72-48-48	72-48 24
	High	72-24-72	72-24-48	72-24-24
Flue-cured tobacco	Low	48-120-144	48-120-120	48-120-96
	Medium	48 96 144	48 96 120	48-96-96
	High	48-72-144	48 72-120	48-72-96
Clovers	Low	0-108-108	0-108-72	0-108-36
	Medium	0-72-108	0-72 72	0-72-36
	High	0-36-108	0 36-72	0-36-36
Other legumes	Low	0 72 72	0 72 48	0 72 24
	Medium	0-48 72	0 48-48	0-48 24
	High	0-24-72	0 24 48	0-24-24
Organic Soils				
All Crops	Low	0 108 108	0 108-72	0-108 36
	Medium	0-72 108	0 72 72	0-72-36
	High	0 36-108	0 36 72	0-36-36

[1]Amounts suggested are for good soil moisture conditions. For fair moisture conditions, amounts should be reduced by one-fourth to one-third and for poor moisture conditions amounts should be reduced one-third to one-half.

TABLE 4.—Suggested Grades and Amounts of Fertilizer for Field Crops in Florida when Results of Soil Tests are Available[1]

	Phosphate Level of Soil	Potash Level of Soil	Suggested Grades and Amounts of Fertilizer[2]						
Minerals Soils		Low	6-9-9 (800)	+	N (48)	or	8-12-4 (600)	+	15-0-15 (320)
	Low	Med.	7-10½-7 (686)[3]	+	N (48)	or	8-12-4 (600)	+	20-0-10 (240)
		High	8-12-4 (600)	+	N (48)	or	8-12-4 (600)	+	N (48)
Perennial grasses		Low	8-8-12 (600)	+	N (48)	or	10-10-5 (480)	+	15-0-15 (320)
	Med.	Med.	9-9-9 (533)	+	N (48)	or	10-10-5 (480)	+	20-0-10 (240)
		High	10-10-5 (480)	+	N (48)	or	10-10-5 (480)	+	N (48)
		Low	10-5-15 (480)	+	N (48)	or	12-6-6 (400)	+	15-0-15 (320)
	High	Med.	10-5-10 (480)	+	N (48)	or	12-6-6 (400)	+	20-0-10 (240)
		High	12-6-6 (400)	+	N (48)	or	12-6-6 (400)	+	N (48)
		Low	4-12-12 (600)	+	N (72)	or	5-15-5 (480)	+	18-0-12 (400)
	Low	Med.	4-12-8 (600)	+	N (72)	or	5-15-5 (480)	+	24-0-8 (300)
		High	5-15-5 (480)	+	N (72)	or	5-15-5 (480)	+	N (72)
Annual grasses		Low	5-10-15 (480)	+	N (72)	or	6-12-6 (400)	+	18-0-12 (400)
	Med.	Med.	5-10-10 (480)	+	N (72)	or	6-12-6 (400)	+	24-0-8 (300)
		High	6-12-6 (400)	+	N (72)	or	6-12-6 (400)	+	N (72)
		Low	6-6-18 (400)	+	N (72)	or	9-9-9 (267)	+	18-0-12 (400)
	High	Med.	7-7-14 (343)	+	N (72)	or	9-9-9 (267)	+	24-0-8 (300)
		High	9-9-9 (267)	+	N (72)	or	9-9-9 (267)	+	N (72)
		Low	4-12-12 (600)	+	N (48)	or	5-15-5 (480)	+	15-0-15 (320)
	Low	Med.	4-12-8 (600)	+	N (48)	or	5-15-5 (480)	+	20-0-10 (240)
		High	5-15-5 (480)	+	N (48)	or	5-15-5 (480)	+	N (48)
		Low	5-10-15 (480)	+	N (48)	or	6-12-6 (400)	+	15-0-15 (320)
Cotton	Med.	Med.	5-10-10 (480)	+	N (48)	or	6-12-6 (400)	+	20-0-10 (240)
		High	6-12-6 (480)	+	N (48)	or	6-12-6 (400)	+	N (48)

TABLE 4.—Continued

	Phosphate Level of Soil	Potash Level of Soil	Suggested Grades and Amounts of Fertilizers[2]					
Minerals Soils		Low	6-6-18 (400)	+ N (48)	or	9-9-9 (267)	+	15-0-15 (320)
	High	Med.	7-7-14 (343)	+ N (48)	or	9-9-9 (267)	+	20-0-10 (240)
		High	9-9-9 (267)	+ N (48)	or	9-9-9 (267)	+	N (48)
		Low	4-10-12 (1200)		or	3-15-3 (800)	+	5-0-25 (480)
	Low	Med.	4-10-10 (1200)		or	3-15-3 (800)	+	6-0-24 (400)
		High	4-10-8 (1200)		or	3-15-3 (800)	+	7-0-21 (343)
Flue-cured		Low	4-8-12 (1200)		or	4-16-4 (600)	+	5-0-25 (480)
tobacco[4]	Med.	Med.	4-8-10 (1200)		or	4-16-4 (600)	+	6-0-24 (400)
		High	4-8-8 (1200)		or	4-16-4 (600)	+	7-0-21 (343)
		Low	4-6-12 (1200)		or	4-12-4 (600)	+	5-0-25 (480)
	High	Med.	4-6-10 (1200)		or	4-12-4 (600)	+	6-0-24 (400)
		High	4-6-8 (1200)		or	4-12-4 (600)	+	7-0-21 (343)
		Low	0-14-14 (771)					
	Low	Med.	0-15-10 (720)					
		High	0-18-6 (600)					
		Low	0-12-18 (600)					
Clovers	Med.	Med.	0-14-14 (514)					
		High	0-16-8 (450)					
		Low	0-9-27 (400)					
	High	Med.	0-11-22 (327)					
		High	0-14-14 (257)					
		Low	0-14-14 (514)					
	Low	Med.	0-15-10 (480)					
		High	0-18-6 (400)					
		Low	0-12-18 (400)					
Other legumes	Med.	Med.	0-14-14 (343)					
		High	0-16-8 (300)					

[1]See footnote 1, Table 2.

[2]The grades listed for crops, except flue-cured tobacco, on mineral soils are not intended to contain minor elements nor natural organic sources of nitrogen. See Table 5 for grades containing minor elements, natural organics or a combination of minor elements and natural organics that may be substituted.

The alternates suggested for non-legumes on mineral soils provide for supplying part of the potash from complete mixtures and part from nitrogen-potash mixtures.

[3]The current Florida Fertilizer Law prohibits the registration of 7-10½-7 as such.

TABLE 4.—Concluded

	Phosphate Level of Soil	Potash Level of Soil	Suggested Grades and Amts. of Fert.
Minerals Soils		Low	0-9-27 (267)
	High	Med.	0-11-22 (218)
		High	0-14-14 (171)
Organic Soils			
		Low	0-12-12 (900)
	Low	Med.	0-12-8 (900)
		High	0-15-5 (720)
		Low	0-10-15 (720)
All Crops[5]	Med.	Med.	0-12-12 (600)
		High	0-14-7 (514)
		Low	0-8-24 (450)
	High	Med.	0-10-20 (360)
		High	0-12-12 (300)

Footnotes

[4]All grades for flue-cured tobacco should contain a minimum of 25 percent of the nitrogen in nitrate form, one-fourth as much soluble magnesium (MgO) as potash, and not more than one-fourth as much chlorine as potash.

[5]Grades suggested for use on organic soils should contain the necessary minor elements in the proper amounts.

TABLE 5.—Suggested Grades of Mixed Fertilizers for Field Crops in Florida, by Ratios and Grade Groups

Ratio	Grades[1] Group 1	Group 2	Group 3
2-3-3	6-9-9	6-9-9	----------
2-3-3	7-10½-7	6-9-6	----------
2-3-1	8-12-4	6-9-3[2]	----------
2-2-3	8-8-12	6-6-9	----------
2-2-1	10-10-5	8-8-4	----------
2-1½-2	10-7½-10	8-6-8	----------
2-1½-1	12-9-6	8-6-4	----------
2-1-3	10-5-15	8-4-12	----------
2-1-2	10-5-10	8-4-8	----------
2-1-1	12-6-6	10-5-5	----------
1-4-2	4-16-8	3-12-6	3-12-6
1-3-3	4-12-12	3-9-9	3-9-9
1-3-2	4-12-8	3-9-6	3-9-6
1-3-1	5-15-5	4-12-4	4-12-4
1-3-2	5-10-15	4-8-12	4-8-12
1-2-2	5-10-10	4-8-8	4-8-8
1-2-1	6-12-6	5-10-5	4-8-4
1-1½-2	6-9-12	4-6-8	4-6-8
1-1-3	6-6-18	5-5-15	4-4-12
1-1-2	7-7-14	6-6-12	5-5-10
1-1-1	9-9-9	8-8-8	6-6-6
0-3-1	0-18-6	0-15-5	----------
0-2-1	0-16-8	0-14-7	----------
0-1½-1	0-15-10	0-12-8	----------
0-1-1	0-14-14	0-12-12	----------
0-1-1½	0-12-18	0-10-15	----------
0-1-2	0-11-22	0-10-20	----------
0-1-3	0-9-27	0-8-24	----------
3-0-1	24-0-8	----------	----------
2½-0-1	20-0-8	----------	----------
2-0-1	20-0-10	----------	----------
1½-0-1	18-0-12	----------	----------

Footnotes

[1]Grades in group 1 to contain no minor elements and no nitrogen from natural organics; those in group 2 to contain minor elements; and those in group 3 to contain natural organics or a combination of natural organics and minor elements.

[2]This grade, with 1 percent soluble magnesium oxide and all potash from sulfate sources, is recommended for use on tobacco plantbeds. Other special grades for flue-cured tobacco are listed and described in Tables 2 and 4.

In late 1953 and early 1954, at the instigation of the author, a series of conferences were held in which Experiment Station workers and industry representatives participated in the examination of the results of recent research on fertilization of field crops and in the development of recommendations based on this information. A total of 18 grades of mixed fertilizer were recommended. Of these, 12 contained nitrogen, phosphorus and potassium, 4 contained phosphorus and potassium only, and 2 contained nitrogen and potassium only, with average nutrient contents of 23.6, 28.5, and 27 percent, respectively.

Although the recommendations that resulted from the 1953-1954 conferences represent a significant step toward the development of sound programs for fertilization of field crops in Florida it has been felt for some time that they should be revised to place more emphasis on easily recognizable soil conditions and to permit use of the results of soil tests in making grade and rate recommendations. The suggestions presented in Tables 1 to 5, which should be self explanatory, represent an attempt at accomplishment of these and other worthwhile objectives.

These suggestions should not be construed as recommendations. It is hoped that they can serve as a basis for discussions with Station workers and industry representatives and as a foundation upon which a satisfactory set of recommendations can be developed.

Expressing Plant Food On An Elemental Basis

W. F. Price*

A little more than a year ago I spoke to the STATE CONTROL OFFICIALS, at their annual meeting, on the subject of oxides and elementals. I must confess that before the talk I felt an uneasiness that some of my audience held the opinion that I was about to commit a treasonable act by opposing a sacred association project.

I should have known better because that fear—like most fears—had no real foundation. Now - - - I know as well as the next person, that not everyone agreed with the viewpoints I expressed. Nevertheless it was a heartening experience to hear directly from many present that they regarded the position I expressed as both tenable and sound.

Today, I must retell the story very much the same a I did a year ago. The basic issues remain exactly the same. I do feel—and with good reason—based upon my correspondence and discussions with control and industry people alike that the climate has changed. Today—and believe me on this point— there is a very real awareness to industry's position and, of course, that is good. We all know in looking back upon certain experiences that it is easy to enthussiastically interest ourselves in a certain project and aggressively crusade for it without regard to consequence because we are convinced that it is good, that it is right, and that because of its obvious virtues to *us,* that it will find universal acceptance.

The subject of the elemental vs. the oxides, when boiled down, is largely a matter of language. It interests me because we must have a common language to free to express our feelings and thoughts. Speaking the same language, we find common interests, likes, and dislikes. Knowledge, expressed in common language, is the backbone of scientific, technological, and economic achievement.

And here you have the real reason why the simple question,

> "Shall we change the expression P_2O_5 and K_2O to P and K in our chemical guarantees?",

has provoked so much discussion during the past few years.

To find the answer to that question, let's go elementary and examine the pros and cons and by whom advanced:

The original proposition was presented by your midwestern colleagues, and later endorsed by the four National Soil Research Committees, the Soil Science Society of America, and the Experiment Station Policy Committees for the North Central Region and the Western Region. By any standard of measurement, that is an impressive roster of endorsers. But, looking closer, we find that these groups are composed of the same people, with the same calling—and that means the same viewpoint. They are the agronomic research workers or their administrators: namely, you or your colleagues. I

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concede that from the standpoint of the working soil scientist there is *no question* but what the arguments advanced do favor a change from the oxide to the elemental in the guarantee, because elemental quarantees promote—

Simplicity of written and spoken communication;
Uniformity of terminology in expressing nutrient content of soils, plant materials, and fertilizers;
Accuracy in stating the ratios of nutrients in a mixture.

To keep our thinking in parallel channels, keep in mind these benefits are primarily for the soil scientist.

Now—let's turn to the next question—the one that still remains. That question in itself contains *all* the doubts and reservations that industry and others have expressed.

The question,—
"Will a change to the elemental benefit the farmer and the local dealer, and if so, will the means necessary to extend the benefits justify the ends.?"

Stripped down, *what if any are the benefits of the change to the most important guy of all?*—the farmer.

Is a change in terminology (desirable to you) also of equal desirability, and equal utility, and equal convenience to the farmer and the dealer? I need not say who constitutes the largest group affected nor whom, under democracy, legislation must benefit.

If you will but take an objective viewpoint, it must be admitted there has been a notable lack of interest by farm groups on this subject. So far the proposition has come up in both the Iowa and Delaware legislatures, but in neither case have the Grange, the Farm Bureaus, nor any other farm organization supported the action nor lobbied in its behalf. I find that our own customers couldn't care less. They are totally unaware of the lack of simplicity, accuracy, or uniformity. They are not concerned in the slightest about these benefits to you. They buy a 7-7-7 for their groves. They obtain their desired response. You know as well as I that if this same 7-7-7 were to become roughly a 7-3-5 instead, it would not produce more boxes, nor lugs, nor bushels of fruit. But now the dealer has the problem of proving that the 7-3-5 was the old 7-7-7. It is even questionable if an interim period of showing both fractional and adjusted ratios would bridge the educational gap. Assume the gap was bridged, would the change benefit the grower? Certainly here in Florida, the championship state on multiplicity of ratios and minor element guarantees, the welter of ratios and decimals would indeed be a spectacle to behold.

Now I am sure you people already had the complexity of this problem figured out, because so far as I know no one from Florida helped to sponsor the elemental idea. As I have already pointed out, it was given birth in the Midwest, where the average state has no more than 20 grades to worry about.

The current change in grain measure from bushels to cwt. can hardly be cited as an argument for the procedure to change the oxides to the elemental basis. Here was not a change to something brand new but merely a substitution to another familiar unit of measure.

This change simplified the farmer's daily chore of calculating yields per acre, in figuring feed formulas, in determining truck and trailer loads, and so on. By contrast, the farmer does not have daily association with fertilizers. For example, here in Florida, the average grower uses fertilizers from 3 to 5 times annually, and in other large agricultural areas of the United States it is even less often. The amount of mental effort necessary to change to a strange and new nomenclature as contrasted with the simple problem of bushels to cwt. would be like comparing the Atlantic Ocean to Lake Okeechobee.

As already pointed out, interest on the part of plant food users is simply non-existent. I can assure you it will remain dormant unless the change is forced by law upon the consumer. If the issue is forced, the reaction will be one of confusion, complexity, and resentment.

The fertilizer dealer, the man who must support the county agent and help carry the message to the farmer, would be completely frustrated after his first attempt to explain the new rations. Can you imagine the reaction of his customer when the dealer says,

> "The old 1-1-1 ratio has been changed to a 2-1-2 on the new basis. It's not really the old 1-1-1, but a 1-0.44-0.83, but none the less the experiment station people say it will work."

Admittedly this is purely a flight of my imagination, and thank goodness it hasn't happened yet. But those are the types of explanations that could happen under an elemental guarantee, and if this situation should develop, you guess what the farmer, the most important man in this chain, is going to think. He has never bothered himself with oxides and elements, and doesn't want to. All he has had time for in his busy and productive life has been to check the numbers: 4-10-7—9-9-9—4-12-12, quoted in the extension bulletin, or in the farm journal, or hammered on year after year by the county agent.

If the elemental change became a reality, the farmer would think we didn't know what we were talking about. In the confusion that is bound to remain for years until the new basis is universal, and the old basis completely a thing of the past, he would most certainly lose faith in us all.

How many years it will take to develop acceptance by the farmer of this new language of fertilizers is an unknown quantity. How many reams of paper for new bulletins explaining the change, how many man-hours diverted from productive work to explaining, or attempting to explain, is equally unknown.

Frankly, I am frightened by the prospect of confusion, of resistance, by the key to agricultural prosperity, the farmer, just because of a capricious change in language.

But frightened or not, let us assume that the change is made, and that after a generation, everybody begins to understand what is meant by N, P, and K. Assume that the libraries are filled with written explanations and justifications. Assume that the frustrated dealers and producers, and the confused farmers of the "generation of oxide reduction" have passed on and have been gathered to their fathers, and

a bright, unconplicated new breed is on hand to make, sell, and use this N.P.K product.

Will the elements make clearer what's in the bag, or grow the corn taller than the oxides: Will the agronomists' findings be utilized more quickly and more profitably by the farmers? Will N, P, and K make a more prosperous agriculture? Will that large segment of industry that depends on a healthy agriculture find it easier to render maximum service to its customers at a fair profit?

I think a good answer to these questions is that a mere change of language will not increase our production, knowledge, or prosperity.

Might I suggest that this profitless problem of nomenclature be shelved? There are so many other important projects to work on—to concentrate on the needed development of knowledge and research in the agricultural field, and to disseminate that knowledge and results of research . . . . rather than muddying up the waters with an excursion in semantics.

The soil and crop scientists of the nation have provided the basis for a fabulous increase in production per farm worker. The high quality of farm products today is the result of patient and devoted research, and an excellent communication system between the scientist and the farmer. I urge you not to jam the airways and slow down the application of new important discoveries which unimpeded, will lead to a fuller, more satisfying life for us all.

Sampling Of Mixed Fertilizers*

John G. A. Fiskell, W. H. Kelly and G. M. Volk**

The sampling of mixed fertilizer is performed to determine if the fertilizer meets the guaranteed analysis on the tag within the limit of tolerance set by law. In drawing the cores for the composite sample the assumption is made that each ingredient in the mix is withdrawn in exact proportion to that in the formulation of the ingredients. Otherwise, an unbalanced or biased sample results, which introduces error. To achieve the desired accuracy, not only must the sampling device take an accurate sample but the fertilizer must be well mixed and possess the true amount of ingredients necessary for the guaranteed analysis. Other factors which determine the variability of the samples drawn are the fertilizer grade, proper construction of the sampling device, the number of cores taken, the condition of the fertilizer and the particle size distribution. The processing of the sample, including sub-sampling, grinding and chemical analysis, is often involved also in the accuracy of the results of the fertilizer analysis.

Florida has taken the lead in recognizing the factors involved in the sampling of mixed fertilizer. Investigations since 1952 have been conducted under the Florida Fertilizer Conrol Research Project, the leaders of which represent the Florida Fertilizer Industry, the State Department of Agriculture and the Agricultural Experiment Station. In studies made by this group, careful sampling of the ingredients entering the mix, close supervision of the mixing process, and detailed sampling of the mix from the belt, bags and bulk have yielded research data on the accuracy of the sampling and clarified the factors involved. This work has been expensive in terms of the tonnage used and time-consuming because a large number of samples were analyzed. Interpretation of the resulting data has been made on a statistically sound basis.

This paper reviews progress made in the sampling of mixed fertilizer and presents evidence of several of the associated factors.

HISTORICAL INFORMATION

Organization of the sampling of mixed fertilizer probably dates back to the work of Wiley in his control laboratory at Purdue University. The grain sampler tube was used and has since become known as the Indiana type of sampling tube. This tube is made with a pointed solid core at the end. The fertilizer enters a slot usually ½ inch wide and 30 inches long extending from the end of the core to the handle. Various modifications of this tube have been tried, in-

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cluding a double tube which permitted sealing off the sample as it was withdrawn from the bag. Studies on the Indiana sampler were reported in 1917 by Lodge (12), in 1922 by Haigh (9), Kellogg (11) and others (10, 15) and confirmed its accuracy and its ease of penetration of bags. Wiley (13) also found this type of tube to be accurate over his years of experience. A survey of sampling tubes used by 32 states was made in 1941 (16) and 18 of them used a slotted single brass tube like that used in Florida. Final action by the referees on sampling for the Association of Official Agricultural Chemists in 1944 (5) led to official directions for sampling (5) being stated as follows:

> "Use slotted single tube, slotted double tube or slotted tube and rod, all with pointed ends."

Allen (1, 2) studied single and double tube Indiana-type samplers and found little difference in chemical composition drawn by these tubes. In 1955 Miles and Quackenbush (14) reported studies on a large number of fertilizer grades and calculated odds of 1 in 100 of a sampling failing to pass tolerance. They showed also that the use of two riffle reduced samples prior to grinding increased the precision greatly and this was confirmed in other work by Allen (3, 4).

Florida was the first state to investigate actual recovery tests of ingredients input against the fertilizer analysis found by sampling at the fertilizer plant. Most control officials and the fertilizer industries within their states must therefore have found the tolerance and number of penalties assessed in reasonable balance. On the other hand, in Florida, the use of pelletized nitrogen sources, particularly in grades without phosphate, led to an increased number of penalties being assessed for failure to meet the nitrogen tolerance. Many members of the fertilizer industry were convinced that the guaranteed nitrogen and some overage had been put in their mixes, even when the samples failed to pass the tolerance limit. Therefore a project for studying the sampling efficiency was outlined and developed by interested parties. The phases of the project to be studied by the Soils and Agricultural Engineering Departments were named the "development of adequate sampling procedures for mixed fertilizers."

FERTILIZER RECEARCH CONTROL TESTS

The cooperative examination of sampling efficiency was begun at two fertilizer plants in Tampa September 27 and 28, 1954. Ten bags were sampled for each composite sample from the bottom, center and top bags in separate fashion from bags piled 6-deep in the truck. Bulk goods were sampled in the official manner. Samples at the mixer discharge were taken within the plant using a cup with some fertilizer spilling over in the process. Results of this study are shown in Table 1. Full details of the data are not given to conserve space. These data revealed satisfactory sampling of the 4-7-5, 4-8-8, and 4-10-7 grades. However, a serious undersampling of nitrogen and a corresponding positive bias or oversampling of the potash occurred for the 8-0-8, 8-0-12, 10-0-10 and 12-0-10 grades. This bias was consistent

TABLE 1.—THE BIASES AND STANDARD ERRORS OF SAMPLES OF SEVEN FERTILIZERS* TAKEN ON SEPTEMBER 27-28, 1954

Fertilizer Grade and Goods Sampled	Total Nitrogen (%N)		Potash $\%K_2O$	
	Bias**	S.E.	Bias**	S.E.
4-7-5, Bags	+.17	—	—.06	—
4-7-5, Within Plant	+.18	—	—.13	—
4-8-8, Bags	+.19	—	—.23	—
4-8-8, Within Plant	+.19	—	—.36	—
4-10-7, Bags	+.31	—	—.07	—
4-10-7, Within Plant	+.31	—	—.15	—
	Mean	.13		.25
8-0-8, Bags	—.28		+.38	
8-0-8, Bulk	—.59		+.52	
8-0-8, Within Plant	—.02		+.14	
8-0-12, Bags	—1.02		+1.25	
8-0-12, Bulk	—1.11		+1.39	
8-0-12, Within Plant	—.45		+.46	
10-0-10, Bags	—1.15		+.66	
10-0-10, Bulk	—1.16		+.64	
10-0-10, Within Plant	—.93		+.46	
12-0-10, Bags	—1.68		+1.05	
12-0-10, Bulk	—1.21		+.62	
12-0-10, Within Plant	—.67		+.35	
	Mean, bags	1.05		.61
	Mean, bulk	.57		.72
	Mean, within plant	.60		.59

*From the "Statistical Report on Chemical Analysis of Seven Fertilizer Mixtures" by D. B. Duncan and J. G. Boring (6).

**Bias was calculated as the difference between the input into the mix and the mean value found in the samples from the mix.

only for the grades tested without phosphate. Analyses by both the state and the commercial laboratory, segregation and sample splitting made small contributions to the sample error. Both bagged goods and bulk goods had more bias than samples drawn by the cup within the plant.

Sieve analysis of these samples revealed that particles above 20-mesh sieve size, which meant the pelletized nitrogen, were not getting into the sample in sufficient amount and an over-abundance of particles between 20-mesh and 100-mesh sieves were entering the sample (7). Fiskell and Chew (7) showed further that calculation of the bias for nitrogen from the sieve analysis, knowing the particle size distribution of the ingredients, gave quite similar magnitude to the bias found by the chemical analysis. Similarly the potash value was excessive from the sieve analysis data in line with that found chemically. Further evidence of this relationship is dealt with in a later section.

A second trial of sampling efficiency was conducted at two fertilizer plants in Tampa March 20 and 21, 1956. The purpose of this study was to obtain data on the sampling of 6-4-8, 8-8-8, 10-4-10, 12-6-6, 0-8-24 and 10-0-12 fertilizer grades. Both bagged and bulk goods were sampled in triplicate. The data in condensed form are presented in Table 2. Chief features of these data were that the

TABLE 2.—The Biases and Standard Errors of Several Fertilizers Sampled March 20-21, 1956*

Fertilizer Grade and Goods Sampled	Total Nitrogen (%N)			Potash (%K_2O)		
	Bias	Bias Mfr.	S.E.	Bias	Bias Mfr.	S.E.
6-4-8, Bags	+.50	—.05	0.16	—.47	—.47	0.17
6-4-8, Bulk	—.03	+.08	.26	+.29	—.09	.39
8-8-8, Bags	+.25	—.10	.06	—.26	—.96	.40
8-8-8, Bulk	+.26	+.14	.01	+.35	+.20	.13
10-4-10, Bags	—.07	—.07	.20	—.46	—.48	.18
10-4-10, Bulk	—.57	+.08	.53	+.62	—.07	.19
10-4-10, Bulk, lab. split	—.01	+.08	.13	+.44	—.07	.40
0-8-24, Bags	—		—	—.96	—1.01	.61
12-6-6, Bags	+.18	—.04	.32	—.51	—.70	.08
12-6-6, Bulk	+.19	+.11	.38	+.36	—.14	.09
12-6-6, Bulk, lab. split	—.40	+.11	.45	+.68	—.14	.25
10-0-12, Bulk (East)	+.20	—.08		—.28	—.28	
Bulk (Center)	—.83	—.08		+1.42	—.28	
Bulk (West)	+2.72	—.08		—4.88	—.28	

*From a Report to the Technical Committee of the Florida Fertilizer Control Research Project compiled by D. B. Duncan and G. M. Volk.

biases for nitrogen are small for bagged goods for all grades and the standard errors are low. The exception was the manufacturer's bias for the muriate of potash, which explained almost all of the overall negative bias found for potash. In the bulk goods only the 10-4-10 and 10-0-12 yielded samples with negative bias for nitrogen exceeding the tolerance; standard errors were also much higher than for the bagged goods. The above mixtures were visually damper than those used in the first trial.

In the third trial, July 24, 1957, at Tampa the real efficiency of several sampling devices was tested by analyzing each core as well as the composite samples. This permitted comparing the standard error and bias for each device and computing the number of cores necessary for a specified sampling accuracy. In line with the above tables, Table 3 shows the data only for bias and standard error. In terms of bias, the Indiana type samplers were not able to sample nitrogen as accurately as the Florida open-mouthed tapered tubes D or E or the belt samples which are described later. Moreover, the standard error was higher for the Indiana-type tubes. This means more cores must be taken to get the same accuracy as found for the other sampling devices using fewer cores. This evidence was obtained on the 10-0-10 fertilizer (containing 6 units MgO) which contained nitrogen derived from pelleted ammonium nitrate and nitrate of soda and which is usually considered difficult to sample accurately. The 8-6-8 fertilizer derived 1.42, 1.22 and 4.22 percent of nitrogen from Peruvian guano, Chicago sludge and ammonium nitrate, respectively, and 22.2 percent of the fertilizer was sulfate of potash magnesia, so that this fertilizer also could be considered difficult to sample.

TABLE 3.—The Biases and Standard Error of Several Sampling Devices Used to Sample 10-0-10-6 and 8-6-8-4 Fertilizers on July 24, 1957

Fertilizer Grade, Sample Device and Goods Sampled	Total Nitrogen (%N)		Potash (%K_2O)	
	Bias*	S.E.**	Bias*	S.E.**
Small Indiana-type tube				
10-0-10-6, Bags	—0.25	0.30	—.01	.20
10-0-10-6, Bulk	—1.48	.21	+.79	.11
8-6-8-4, Bags	—.46	.14	—.31	.11
8-6-8-4, Bulk	—.99	.18	+.37	.18
Large Indiana-type tube				
10-0-10-6, Bags	—.37	.18	+.20	.18
10-0-10-6, Bulk	—1.16	.40	+.17	.25
8-6-8-4, Bags	—.29	.23	+.05	.11
8-6-8-4, Bulk	—.71	.27	+.17	.26
Modified Large Indiana-type tube				
10-0-10-6, Bags	—.36	.35	+.38	.21
10-0-10-6, Bulk	—.72	.27	+.38	.19
8-6-8-4, Bags	—.26	.15	+.14	.10
8-6-8-4, Bulk	—.70	.29	+.16	.27
Florida tube, D				
10-0-10-6, Bags	—.02	.25	+.25	.15
10-0-10-6, Bulk	—.79	.34	+.68	.27
8-6-8-4, Bags	—.20	.16	+.03	.08
8-6-8-4, Bulk	—.91	.20	+.63	.16
Florida tube, E				
10-0-10-6, Bags	—.02	.18	—.04	.15
8-6-8-4, Bags	—.05	.08	—.04	.08
Small Wedge-Cup Sampler				
10-0-10-6, Belt Discharge	—0.13	0.12	+.27	0.081
8-6-8-4, Belt Discharge	—.22	.040	+.01	.082
Large Wedge-Cup Sampler				
10-0-10-6, Belt Discharge	+.26	.096	+.23	.11
8-6-8-4, Belt Discharge	—.26	.061	+.20	.073
Narrow Belt-Cup Sampler				
10-0-10-6, Moving Belt	+.19	.078	—.11	.13
8-6-8-4, Moving Belt	—.14	.030	+.03	.065
Wide Belt-Cup Sampler				
10-0-10-6, Moving Belt	+.01	.096	+.11	.072
8-6-8-4, Moving Belt	—.13	.028	—.01	.055

Bias calculated using the materials analysis and the means of composite and individual core samples.

**Standard error calculated from 15 individual core analysis in the case of belt and bag sampling and 8 for bulk sampling.

The satisfactorily low bias and standard error for the two Florida tubes and belt samplers are significant because any decrease in bias increases the effective tolerance. For instance, if the legal tolerance is 0.50 percent nitrogen and the sampling bias is -0.40, the effective tolerance is 0.10; 0.40 overage is necessary to compensate for the decrease in tolerance. Standard error sets the chances that a certain number of samples will be lower than the legal tolerance permits. For example, a standard error of 0.4 and a legal tolerance of 0.50 have the probability of 12 deficiencies per 100 samples whereas a standard

TABLE 4.—Particle Size Distribution Sample Size and Percent Nitrogen in Cores of 10-0-10-6 and 8-0-8-6 Fertilizers Drawn by Several Sampling Devices.

Sample Device and Goods Sampled	Sample Weight	Sieve Analysis			Ratio* C/F	Ratio** MC/F	Total N
		on 10-mesh	on 20-mesh	passes 20-mesh			
	gms.	%	%	%			%
				10-0-10-6 Fertilizer			
Wedge-Cup	780	13.3	44.4	42.3	1.36	1.05	9.10
at mixer	945	13.2	45.1	41.7	1.40	1.08	10.22
discharge	1132	13.4	45.0	41.6	1.40	1.08	9.40
	683	14.1	44.1	41.9	1.39	1.05	9.95
	662	11.1	47.8	41.1	1.32	1.16	10.14
Mean	840	13.0	45.3	41.7	1.37	1.08	9.76
at belt	656	16.8	39.0	44.2	1.26	0.88	7.67
discharge	963	14.8	46.1	39.1	1.56	1.18	11.63
	1054	13.4	46.2	40.4	1.47	1.14	11.00
	956	11.3	41.3	47.4	1.11	0.87	8.63
	959	12.0	47.5	40.5	1.47	1.17	12.53
Mean	918	13.7	44.0	42.3	1.15	1.05	10.29
Small Indiana-Type	105	11.8	39.9	48.3	1.07	0.82	8.61
Tube on	120	9.4	39.7	50.9	0.96	0.78	8.89
bulk goods	103	10.6	44.2	45.3	1.21	0.98	9.34
	130	9.4	42.2	48.4	1.07	0.87	9.28
	121	6.7	39.0	54.3	0.84	0.72	7.83
Mean	116	9.6	41.0	49.4	1.03	0.83	8.79
Tube on	121	12.8	45.6	41.5	1.41	1.10	10.14
bagged goods	100	11.5	47.0	41.6	1.43	1.13	9.00
	134	13.6	48.1	38.3	1.61	1.26	10.18
	124	14.8	44.4	40.8	1.45	1.09	9.84
	129	12.1	47.4	40.5	1.46	1.17	9.32
	122	13.9	44.9	41.2	1.43	1.09	9.69
Mean	118	13.1	46.2	40.7	1.47	1.14	9.69
Large Indiana-Type Tube	193	11.0	40.4	48.6	1.06	0.83	8.96
on bulk	235	11.5	40.2	49.3	1.03	0.81	8.88
goods	306	10.8	45.8	43.3	1.31	1.06	10.77
	258	11.5	42.7	45.8	1.18	0.93	9.64
	234	7.9	43.4	48.7	1.05	0.89	8.15
Mean	204	10.3	42.5	47.2	1.11	0.90	9.28
Large Indiana-Type Tube	248	11.7	43.0	45.3	1.21	0.95	9.70
on bagger	323	14.6	42.9	42.6	1.35	1.01	9.30
goods	324	14.5	48.5	36.9	1.52	1.31	12.52
	229	20.1	39.5	40.4	1.56	0.98	10.24
	336	12.7	42.0	45.4	1.20	0.92	9.46
	261	13.0	43.2	43.8	1.51	0.99	9.75
Mean	287	14.4	43.2	42.4	1.39	1.03	10.16
Florida Tube C	122	12.2	45.8	42.0	1.38	1.09	9.78
on bagged	130	12.5	44.5	43.0	1.32	1.04	10.08
goods	147	11.7	50.0	38.4	1 61	1.30	11.87
	146	12.3	43.6	44.2	1.26	0.99	9.70
	150	12.3	47.3	40.4	1.48	1.16	9.89
	127	12.2	41.9	45.9	1.18	0.91	9.26
Mean	137	12.2	45.5	42.3	1.37	1.08	10.10

TABLE 4.—CONTINUED.

Sample Device and Goods Sampled	Sample Weight	Sieve Analysis			C/F Ratio*	MC/F Ratio**	Total N
		on 10-mesh	on 20-mesh	20-mesh passes			
	gms.	%	%	%			%
				10-0-10-6 Fertilizer			
Florida Tube D	327	11.8	42.2	46.0	1.17	0.92	9.69
on bagged	385	12.5	44.3	43.3	1.31	1.02	10.70
goods	398	11.6	44.4	44.0	1.27	1.01	10.54
	368	13.6	42.1	44.3	1.26	0.95	9.68
	332	13.3	44.9	41.9	1.39	1.07	10.23
	427	13.4	39.3	47.3	1.11	0.83	9.06
Mean	373	12.7	42.9	44.5	1.25	0.97	9.98
Florida Tube E	614	12.2	43.7	44.1	1.27	0.99	9.90
on bagged	582	15.1	46.2	38.7	1.59	1.20	11.90
goods	650	12.8	40.7	46.6	1.15	0.87	9.32
	728	12.0	43.4	44.6	1.24	0.97	9.39
	665	13.1	43.3	43.6	1.29	0.99	10.32
	663	13.9	43.9	42.2	1.37	1.04	10.06
Mean	650	13.2	43.5	43.3	1.32	1.01	10.15
Small Indiana-	142	16.6	41.5	41.9	1.39	0.99	9.09
Type Tube	156	14.1	38.7	47.2	1.12	0.82	8.84
on bagged	156	15.8	41.0	43.2	1.31	0.95	8.70
goods	135	13.5	38.7	47.9	1.09	0.81	8.53
	172	13.8	40.4	45.8	1.19	0.88	8.68
Mean	152	14.8	40.0	45.2	1.22	0.89	8.76
				8-0-8-6 Fertilizers			
Large Indiana-	330	16.8	41.2	42.0	1.41	0.98	9.12
Type Tube	374	20.1	43.6	36.3	1.76	1.20	9.83
on same	388	19.8	40.8	39.4	1.54	1.04	9.59
bagged goods	334	16.1	41.0	42.9	1.33	0.95	9.12
	398	15.4	41.4	43.2	1.32	0.96	9.10
Mean	365	17.6	42.6	39.8	1.47	1.03	9.35
Florida Tube D	409	17.8	39.9	42.3	1.37	0.94	9.04
on same	490	12.7	39.0	48.2	1.07	0.81	8.18
bagged goods	503	16.1	39.6	44.3	1.26	0.90	9.05
	476	13.8	40.7	45.5	1.20	0.89	8.83
	693	12.6	38.3	49.0	1.04	0.78	8.09
Mean	514	14.6	39.5	45.9	1.19	0.86	8.64

C/F ratio signifies fractions combined on 10-mesh and 20-mesh sieves divided by fraction passing the 20-mesh sieve.

**MC/F ratio signifies fractions on 20-mesh sieve divided by fraction passing the 20-mesh sieve.

error of 0.2 or smaller gives less than one deficiency per 100 samples.

Sampling bulk fertilizer in the above trials is a more difficult task than sampling bagged goods or fertilizers within the plant. The tests on 8-8-8, 6-4-8, and 12-6-6 showed little bias for nitrogen. But 10-4-10, 8-8-6 and several grades without phosphate had a higher negative bias for nitrogen than the legal tolerance. This made it difficult to

draw a sample that would pass. In such cases it might be necessary to sample from the belt.

Bulk goods containing pelleted nitrogen sources are difficult to sample because the pellets roll towards the sides. This provides a gradient of nitrogen rather than a homogenous mix and how to sample such a gradient will require further research. The nitrogen gradient is caused by the greater momentum of the larger particles, which include most of the pelletized nitrogen sources. The potential energy of a particle having a mass m falling a distance h with an acceleration g due to gravity, is

$$E = mgh.$$

The momentum of mass m falling with a velocity v, is

$$M = mv.$$

Since all fertilizer particles fall the same distance, the momentum is directly proportional to the mass of the particle. The large particles have many times the momentum and potential energy of the small particles. The height of fall and to some extent the speed of the conveyor belt govern the magnitude of the momentum. The pelletized nitrogen materials from their relatively larger inertia can travel further from the center of the falling fertilizer. The distance is governed by collisions with other particles, the most numerous being smaller particle sizes. Momentum differences can result therefore in some segregation of fertilizer ingredients.

REGRESSION FUNCTIONS

As mentioned above, the sampling of mixed fertilizer requires each ingredient to be sampled in the same proportion as that entering the mix. Using several sampling devices, individual cores of a 10-0-10-6 and 8-0-8-6 fertilizer were taken at a fertilizer plant. In Table 4 are shown the sieve analysis data and total nitrogen found in these cores, the ratios of large to small particle size fractions and sample weights. The regression function significant by the t test, description of the sampling devices and the regression functions obtained are given below.

Wedge-cup sampler. The wedge-cup sampler is used for the mixer or belt discharge samples and has a 15/16" X 6" opening and a base 5" X 6" with a handle attached. The regression equation of percent nitrogen to the percentage of particles y greater than 20 mesh but passing a 10 mesh sieve, is

$$\%N = 11.14\ y - 1.78.$$

However, belt discharge samples having percentage of particles greater than 20 mesh expressed as z have the relationship

$$\%N = 9.35\ z - 2.56.$$

which is comparable to the function of particles y size

$$\%N = 12.42\ y - 2.73.$$

The negative intercept suggests some of the samples missed part of the nitrogen and the slopes of 9.35 and 12.42 indicate the high degree of correlation occurring. It is worthy of note that the standard error was .54 and .32 for nitrogen in the mixer discharge and belt discharge, respectively, which has been reported elsewhere by the senior

author (8). The standard error in the 1957 trials reported above is .12. This decrease in variability is attributed to passing the sample carefully across the fertilizer stream in the trial given in Table 3, whereas a more random sampling approach was used in the cases listed in Table 4. The means of these samples are 10.08, 10.27 and 10.30, respectively, which illustrates the value of individual core analysis in exposing variability.

The small Indiana-type tube. This tube is 31" long with a 1" solid cone, a diameter of ¾" and 3 slots of 9" in length. The regression functions are

$$\%N = 6.36 + 2.31z \text{ and } \%N = 6.15 + 3.13y.$$

including both bulk and bag sampling. The mean for the bag samplings is 9.69 %N with a standard error of .23 and the regression function is also not significant. This signifies insufficient nitrogen particles retained in the cores. The 8-0-8 fertilizer cores drawn by this tube gave 8.78 %N with a standard error of .18. The regression function was not significant at the 5% level of probability.

The large Indiana-type tube. Dimensions of the large Indiana-type tube are 29" in length, with a 2¼" solid cone tip and diameter of 1¼" with slots of 9" and 11" in length. The mean is 10.16 %N with a standard error of 0.26 and the regression functions for overall bag and bulk samplings are

$$\%N = 4.40 + 4.22z \text{ and } \%N = 2.19 + 7.80y.$$

The function for bulk and bag sampling is respectively

$$\%N = 0.47 + 7.83z \text{ and } \%N = 1.98 + 8.07z.$$

and also $\%N = 2.01 + 7.94y$.

In the 8-0-8 fertilizer the functions are

$$\%N = 6.63 + 1.88z \text{ and } \%N = 6.19 + 3.09y.$$

These regression functions show that the nitrogen is being sampled better by this tube than the small one.

Florida tube C. The development of Florida tube C arose from the Volk-Myers open-end tapered tube (17). The tube has a ¾"" opening, is 18" long with ¼" taper per foot and made of 26 USS gage stainless steel. It is fitted with a solid brass bushing and pressed wood fiber block which is made for attachment to a small electric reciprocating hammer. The mean obtained is 10.10 with a standard error of 0.21 and the regression functions for the combined data on bulk and bag cores, are

$$\%N = 4.23 + 5.00z \text{ and } \%N = 3.85 + 5.87y.$$

Florida tube D. A longer and larger tube than Florida tube C, the D model, has an opening 1¾" and length of 36" and is fitted for the electric hammer. For the 10-0-10 fertilizer sampled in bags the regression functions are,

$$\%N = 3.98 + 4.78z \text{ and } \%N = 3.38 + 7.73y.$$

The mean is 10.06 with a standard error of 0.15. The function is not significant for the bulk sampling, indicating the nitrogen pellets were not present sufficiently at the sampling locations. For the 8-0-8 fertilizer the mean is 9.35 showing overage and the regression functions are

$$\%N = 5.50 + 3.23z \text{ and } \%N = 3.44 + 6.84y.$$

The differences in the equations show the greater regression for the y size of particles.

Florida tube E. The upper end of Florida tube D cut off 18" down the shaft, forming a 1 5 8" opening, is termed Florida tube E. The mean of cores of the 10-0-10 fertilizer is 10.15 with a standard error of .10. The regression functions are,

$$\%N = 3.31 + 5.94z \text{ and } \%N = 1.86 + 8.21y.$$

The characteristics of this tube are more like the D tube than the C tube and all three have slopes similar to the large Indiana-type tube.

Other correlation functions. The relationship of nitrogen analyses to particle size distribution was stressed in the above. Similar functions for potash also should exist. In laboratory studies, Volk and Myers (17) found that there was a highly significant inverse correlation between recovery of nitrogen and potash in a 10-0-10 fertilizer. The regression function, is

$$\% \text{ potash recovered} = 145 - .45\ \%N \text{ recovered.}$$

They also reported that fertilizer containing 0.44% water was sampled more efficiently than the same dry mixture in either compact or loose condition.

The senior author has noted that setting up or compaction of 10-0-10 fertilizer does not become serious until 1.5% moisture is present. Some improvement in the sampling properties of mixed fertilizer might be attributable to the moisture content. The moisture would need to be kept low enough to maintain the free-flowing properties and yet not so dry that particles move too freely in the fertilizer mixture.

CONCLUSIONS

The use of the small Indiana-type tube as a sampling device may be satisfactory for low analysis complete fertilizer grades. However, it would appear from these limited data that the bias and standard errors are too high for accuracy in mixtures containing a high proportion of pelletized or larger particles. This may be due either to the sample core being too small or to incomplete sampling and retention of large particles because about one third of the sample is exposed to changes on withdrawing the core. The large Indiana-type tube takes about three times as large a sample per core as the small Indiana-type tube and has about the same relatively exposed sample area. The Florida tools have the advantage that once the core is taken it is protected from subsequent change in withdrawal from the fertilizer and is taken continually into the tube. The bias and standard errors of the Florida tubes D and E are sufficiently low for precision sampling and indicate a true core is being taken. The new wedge-cup and belt sampler scoops appear suitable also for precision sampling of fertilizer from the belt discharge and belt, despectively. This should be of value in sampling fertilizer for bulk goods. In the above studies it is evident that bagged goods can be sampled accurately, but bulk goods having a nitrogen gradient towards the edges of the load are not likely to be adequately sampled by either type of tubes probed into the top of the load.

The regression functions of nitrogen in the sample to the ratios of the particle size fractions indicate, as is to be expected, that pelletized sources are sampled correctly when the mean and guaranteed value are closely alike. The intercept and slope of these functions varies with the sampling device and should be similar for tools giving comparable accuracy. The exact function requires more observations and tests on more grades than given in the above cases, but this type of information is useful in explaining sampling difficulties. Individual core analysis rather than composite analysis only is recommended where maximum information on the sampling of mixed fertilizer is sought.

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CONTRIBUTED PAPERS

Yields And Quality Of Peppers As Affected By Ammonium Nitrate And Sulfate Of Potash Treatments

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The acreage planted to peppers on the sandy soils of the Lower East Coast of Florida has increased rapidly in recent years, and amounted to over 6,000 acres during the 1955-56 season (1). For the past two seasons, the total monetary value of peppers sold on the Pompano State Market has been more than that of beans sold on the same market.

Yield responses to nitrogen and potash fertilization have been reported on spring-harvested peppers (2, 3). No research has been reported, however, on responses to fertilization of winter-harvested peppers on the Lower East Coast.

EXPERIMENTAL PROCEDURE

Rates of nitrogen and potash fertilization for peppers were investigated in a 3x3 factorial experiment with four replications conducted during the 1955-56 and 1956-57 growing seasons. The experiment was located at the Plantation Field Laboratory near Fort Lauderdale on Davie fine sand. The water table was maintained at 24 inches during both seasons. Plots were seeded to Florida Giant peppers on September 12, 1955, and September 5, 1956.

Each year the experimental area received one ton of dolomitic limestone per acre. In addition, all plots received 400 pounds 5-10-5 containing 0.4% CuO, 0.6% MnO, 0.4% ZnO, 0.2% B_2O_3, 0.4% Fe_2O_3, and 2.0% MgO per acre at planting time in bands. Also, two sidedressings of the same mixture were applied at the rate of 400 pounds per acre to all plots later in the season.

Differential treatments of nitrogen and potash were made at biweekly intervals for a total of ten applications to supplement the basic fertilization described above. Ammonium nitrate and sulfate of potash were supplied in each application to furnish all combinations of 20, 30, and 40 pounds of N and K_2O per acre. In treatments coinciding with applications of complete fertilizer, ammonium nitrate and sulfate of potash were decreased by amounts equivalent to the amounts of the respective elements contained in the complete fertilizer. The nitrogen-potash applications were broadcast over the entire soil area until the plants covered the beds, after which they were applied only in the furrows. Each received identical treatment during both seasons.

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Plots were harvested at 10-day intervals beginning 113 days after seeding in 1955, and 99 days after seeding in 1956. As the crown fruit (first set) are larger and higher in quality than the limb fruit, which usually suffer damage from wind scars, both early yields and total yields were tabulated.

RESULTS AND DISCUSSION

During the hot, dry fall of 1955, early yields of U. S. Fancy peppers were reduced linearly as the amount of nitrogen applied at bi-weekly intervals increased from 20 to 40 pounds of N per acre (Table 1). In contrast, during the more nearly normal conditions of temperature and rainfall in 1956, no significant differences in early Fancy yields were obtained by varying the rates of nitrogen application (Table 1). Although the early U. S. Fancy yield was lower in 1956, the 1956 combined early yield of U. S. Fancy and U. S. No. 1 was higher than the 1955 combined yield, made up mainly of U. S. Fancy peppers. The deleterious effects of high nitrogen fertilization on early yields in 1955 may have been due, in part, to an increased blossom and fruit drop which was observed in the plots and also in commercial fields receiving heavy nitrogen applications.

Reductions in early U. S. Fancy yields in 1955 resulting from the higher rates of nitrogen fertilization were offset by increases in late yields. Consequently, there were no significant differences in total yields of marketable peppers due to differential nitrogen treatments in 1955 (Table 2, 3). Differential nitrogen treatments did not significantly influence total yields of U. S. Fancy, or combined U. S. Fancy and U. S. No. 1 yields, in the 1956-57 season (Table 2, 3).

During the 1956-57 season, the number of peppers exhibiting blossom-end rot was greatest on plots receiving the highest rate of nitrogen fertilization (40 pounds N per acre bi-weekly) as shown in Table 4. The same trend was noted in the 1955-56 season, although those differences were not significant. The number of blossom-end rot peppers was not significantly affected by the potash treatments.

There were no sunburned fruits in the 1955-56 experiment. The numbers of sunburned fruit in the 1956-57 experiment were smallest at the high rates of application of both nitrogen and potassium as shown in Table 5.

An increase in the bi-weekly rate of potash application from 20 to 30 pounds K_2O per acre increased total yields of U. S. Fancy peppers in the 1955-56 season, but a further increase to 40 pounds K_2O per acre resulted in a significant decrease in yield (Table 2). In the 1956-57 season, an increase in the bi-weekly rate of potash application from 20 to 30 pounds K_2O per acre resulted in significant increases in total U. S. Fancy, and total combined U. S. Fancy and U. S. No. 1 yields (Tables 2, 3). A further increase in rate of potash application did not significantly influence yields. The combined yields for the 1955-56 season as given in Table 3 exhibit differences similar to those of the 1956-57 season.

The combination of bi-weekly applications of 30 pounds per acre each of N and K_2O, in general, produced highest yields of marketable peppers. This combination was significantly greater than any other

TABLE 1.—Accumulated Yields of U. S. Fancy Peppers for First Three Harvests. Plantation Field Laboratory, 1955-57.

(bushels per acre)

Rate of K_2O Applied Biweekly (lbs./A)	Rate of N Applied Biweekly (lbs./A) 20			30			40			Average		
	'55-'56	'56-'57	Total	'55-'56	'56-'57	Total	'55-'56	'56-'57	Total	'55-'56	'56-'57	Total
20	253	110	363	208	91	299	171	163	334	211	121	332
30	263	136	399	241	249	490	209	181	390	238	189	427
40	218	175	393	207	137	344	160	190	350	195	167	362
Average	245	140	385	219	159	378	180	178	358			

TABLE 2.—Total Yields of U. S. Fancy Peppers. Plantation Field Laboratory, 1955-57.

(bushels per acre)

Total K_2O Applied (lbs./A)	Total N Applied (lbs./A) 200			300			400			Average		
	'55-'56	'56-'57	Total	'55-'56	'56-'57	Total	'55-'56	'56-'57	Total	'55-'56	'56-'57	Total
200	365	228	593	302	225	527	318	298	616	328	250	578
300	414	356	770	456	470	926	379	364	743	416	397	813
400	372	404	776	424	356	780	322	425	747	373	395	768
Average	384	329	713	394	350	744	340	362	702			

TABLE 3.—Total Combined Yields of U. S. Fancy and U. S. 1 Peppers. Plantation Field Laboratory, 1955-57.

(bushels per acre)

Total K_2O Applied (lbs./A)	Total N Applied (lbs./A) 200			300			400			Average		
	'55-'56	'56-'57	Total	'55-'56	'56-'57	Total	'55-'56	'56-'57	Total	'55-'56	'56-'57	Total
200	658	739	1397	605	706	1311	543	864	1407	602	770	1372
300	727	962	1689	717	1130	1847	700	967	1667	715	1020	1735
400	721	1089	1810	698	935	1633	658	1056	1714	692	1027	1719
Average	702	930	1632	673	924	1597	634	962	1596			

TABLE 4.—Number of Peppers Exhibiting Blossom-End Rot. Plantation Field Laboratory, 1955-57.

(number per acre)

Total K_2O Applied (lbs./A)	Total N Applied (lbs./A) 200			300			400			Average		
	'55-'56	'56-'57	Total	'55-'56	'56-'57	Total	'55-'56	'56-'57	Total	'55-'56	'56-'57	Total
200	408	2233	2641	607	2464	3071	669	2464	3133	561	2387	2948
300	484	2772	3256	838	3234	4072	838	5159	5997	720	3721	4441
400	723	1925	2648	731	5926	6657	884	5621	6505	779	3490	4269
Average	538	2310	2848	725	2874	3599	797	4414	5211			

TABLE 5.—Number of Sunburned Peppers, Plantation Field Laboratiry, 1956-57.

(number per acre)

Total K_2O Applied (lbs./A)	Total N Applied (lbs./A)			
	200	300	400	Average
200	12,782	11,088	9,548	11,139
300	9,548	7,469	9,240	8,752
400	9,317	10,010	5,852	8,393
Average	10,459	9,522	8,213	

only for early yields of U. S. Fancy and U. S. No. 1 peppers during the 1956-57 season, however. These relationships are shown in Tables 1, 2, and 3. The same rate of fertilizer application has previously been reported to produce the highest yields in spring-harvested peppers (1).

CONCLUSIONS

Although early yields were reduced in the 1955-56 season as the bi-weekly rate of nitrogen application increased from 20 to 40 pounds N per acre, total yields of marketable peppers were not significantly influenced by the different rates of nitrogen application. Increasing the rate of nitrogen application resulted in increasing the incidence of blossom-end rot, and in decreasing the incidence of sunburning.

Bi-weekly applications of 30 pounds K_2O per care for a total during the season of 300 pounds produced highest yields of marketable peppers on the average.

Highest yields of winter-harvested peppers were obtained, in general, as a result of bi-weekly applications of 30 pounds per acre each of N and K_2O to furnish a total of 300 pounds of each per acre.

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Phosphorus Experiments With Potatoes On The Perrine Marl

John L. Malcolm*

This experiment was undertaken to determine the influence of the rate of application of phosphate fertilizer on the yield of Red Bliss potatoes grown on Perrine marl. It is generally assumed that this marl soil is deficient in phosphorus. The phosphorus content of the virgin soil is low, less than 0.02 percent P. The pH, 7.8, is very close to the point of minimum solubility of soil phosphate. Finally, the marl is extremely fine in texture and provides a great deal of surface on which phosphate can be precipitated.

A series of experiments were reported by Fifield and Wolfe (1), in which the rate of application was varied from 120 to 240 pounds of P_2O_5 per acre. In their earliest experiments the highest rate of application of phosphorus gave the largest yield. In later experiments, however, the value of applying more than 120 pounds of P_2O_5 per acre could not be shown. They concluded that experiments which included lower rates of application of phosphate were needed. In all their experiments with phosphate fertilizer, new locations were chosen for the plots each year. Thus they had no opportunity to observe the cumulative effect of their treatments.

PROCEDURE

The present experiment was located on the East Glade Farm of the Sub-Tropical Experiment Station. The soil and cultural methods which approximated commercial practice were described in a previous paper (2). In this experiment the check, low, medium and high treatments were applied to the same plots in each of four successive years.

The fertilizer in the 1949 season was 4-X-6, with a phosphoric acid content of 0, 4, 8, or 16 percent, applied at the rate of 1500 pounds per acre. In the three years following, a 4-X-5 with 0, 3½, 7, or 14 percent P_2O_5 was used, the same fertilizer used in a companion tomato fertilizer experiment. Both mixed fertilizers contained magnesium and manganese. The phosphoric acid content of the fertilizer applied in 1949 was 0, 60, 120, and 240 pounds per acre. For the remainder of the experiment the rates of application were 0, 52.5, 105, and 210 pounds P_2O_5 per acre. Triple superphosphate was used as the only source of phosphorus in this experiment.

Soil samples were taken in the fall of 1952 at the time the last crop was planted. Water extracts of these samples were analyzed at the Sub-Tropical Experiment Station. The available nutrients were also determined at the Soil Testing Laboratory in Gainesville*, using ammonium acetate solution as the extractant.

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*Thanks to Dr. Herman L. Breland.

RESULTS

During the four years the test was run, no visible symptom of deficiency or toxicity was observed on these plots. The potato vines were uniform in height, vigor and color. The yields are presented in Table 1. Each value is the average of four replicates. Only the yield of No. 1 potatoes is reported, since there was no difference in the proportion of No. 1 potatoes from one treatment to another.

TABLE 1.—YIELD OF NUMBER 1. POTATOES
(POUNDS PER 0.005 ACRE PLOT)*

Phosphate Treatment	Year				Average
	1949	1950	1951	1952	
Check	110.4	56.3	97.1	55.8	79.9
Low	116.7	72.9	95.8	64.8	87.5
Medium	116.7	75.3	93.1	63.9	87.2
High	114.0	73.8	95.4	65.6	86.8

*Yields in pounds per plot multiplied by four equals sacks per acre.

There was no significant difference in yield over the four years or in any single year. In the third year the highest yield was produced by the check, which had not received any phosphorus.

Phosphorus was not detectable in the water extracts of these marl soils. The potassium and sodium contents were similar to those of other vegetable soils. In addition to the moderate sodium levels, conductivity measurements on the extracts showed that the soluble salts were far below the levels at which they could reduce the yield of potatoes.

The results obtained with the ammonium acetate extract are shown in Table 2. Neither the phosphorus nor potassium levels were correlated with individual plot yields. The available CaO on all plots was in excess of 5,600 pounds per acre, and available MgO 3,316 pounds per acre on all plots.

Since no significant response was obtained to the application of phosphate, it may be concluded that the soil at the East Glade Farm contained sufficient available phosphorus for potatoes. This avail-

TABLE 2.—AVAILABLE NUTRIENTS
(POUNDS PER ACRE)

Phosphate Treatment	P_2O_5	K_2O
Check	34	414
Low	42	356
Medium	57	405
High	60	387
L.S.D. 0.05	14	NS
0.01	20	

able phosphorus probably was the accumulation of phosphorus applied in the fertilizer in previous years. The soil tests show clearly that the readily soluble phosphorus increased approximately in proportion to the amount applied.

In adjoining tests, deficiencies of nitrogen, potassium, magnesium and manganese were ruled out as limiting factors in production. In the nitrogen test previously reported (3), particular attention was drawn to the significance of factors other than fertility in determining the yield of potatoes. Temperature, rainfall, and possibly other climatic factors apparently limited to potato yields.

Although these plots were located in the section of the glade subject to occasional salt intrusion, soil tests and the condition of the vines and tubers showed that salt was not a limiting factor during the course of this experiment. Furthermore, the yields equalled the average for the county.

These results are in sharp contrast to the tomato fertilizer experiment in which a very highly significant increase in yield was obtained from the application of phosphate fertilizer (4).

CONCLUSIONS

The phosphorus supply of this soil was sufficient to meet the requirements of Bliss Triumph potatoes under the conditions of this experiment. Four years was not sufficient time to reduce the phosphorus supply to a critical level. No toxicity resulted from 870 pounds of P_2O_5 per acre applied over a four year period.

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Phosphorus Experiments With Tomatoes On Perrine Marl

John L. Malcolm*

The purpose of this experiment was threefold. First, it was to determine the optimum rate of application of phosphorus on tomatoes on the deep phase of the Perrine marl. Second, it was to find what relationship existed between the mineral composition of the tomato plant and the application of phosphate fertilizers. Third, it was intended to provide plants showing typical symptoms of deficiency or excess of phosphorus which might be used to identify similar conditions in commercial fields.

The only previous experiments reported on the rate of application of phosphate fertilizer to tomatoes grown on marl soils were reported by Skinner and Ruprecht (4) in 1930. They ran experiments in two locations in each of two years. In no case did they apply treatments to the same plots in two successive years. The rates of application which they tested ranged from 6 to 360 pounds of P_2O_5 per acre. The maximum yields of tomatoes were obtained from 180 to 240 pounds of P_2O_5 per acre.

The experiment described in this paper was located at the Highlands Farm of the Sub-Tropical Experiment Station. The soil is a deep Perrine marl and the plot area was surrounded by a ditch so that excess water could be pumped off. The general procedure has already been described (1).

The experiment was run for seven years, from 1949 through 1955. For the first five years the rates of application of phosphoric acid were 0, 70, 140, and 280 pounds per acre per year. The last two years these rates were increased to 0, 75, 150, and 300 pounds per acre to conform with other tests. The check, low, medium, and high treatments were applied to the same plots each year. The phosphorus was applied in a mixed fertilizer. In all years triple superphosphate was used as the source.

A number of significant changes were made during the course of the experiment. In most cases they were made to remove controllable factors other than phosphate as the possible limiting factor. In the third year the Grothen Globe variety was replaced with Homestead, which was wilt resistant and showed greater yield potential. In each of the first three years 80 pounds of nitrogen per acre was applied. In 1952 and 1953 this was supplemented by nitrogen from cyanamid which was applied for the control of sclerotiniose. By this time the nitrogen experiment described previously (2) indicated the need for 300 pounds of nitrogen per acre. This amount was used in 1954 and 1955. From 1949 to 1951, 100 pounds of K_2O per acre per year was

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applied. In 1952 and 1953 this was increased to 200 pounds per acre and in 1954 and 1955 to 300 pounds.

Although magnesium was used in the fertilizer the first five years, it was omitted during the last two years, since other experiments had shown that this soil contained sufficient available magnesium for tomatoes. The manganese in the fertilizer was replaced first by a spray of manganous sulfate and then by maneb fungicide.

Leaf samples were taken each of the last four years. These samples were taken at the time of the first picking so that virus diseases, particularly tobacco mosaic, would not be spread by sampling prior to picking. Total nitrogen, phosphorus, potassium, calcium, and magnesium were determined on the oven-dried leaf samples.

At the end of the 1954 season, soil samples were taken for determination of the available nutrient supply. These were analysed by the Soil Testing Laboratory at Gainesville.*

In all appropriate cases, yield, leaf analyses, and soil analysis data were tested by an analysis of variance.

RESULTS

In every year the tomato plants on the check plots were noticeably stunted but never developed the classical symptoms of phosphorus deficiency. Vine growth was very heavy on the high phosphorus plots, particularly in the later years of the experiment when sufficient nitrogen was applied. Because of rank growth on these plots in some seasons, the plants were damaged by the tractor and sprayer, often showed most tobacco mosaic, and were difficult to spray adequately.

The yield data for the seven years of the experiment are shown in Tables 1 and 2. The value reported for each treatment each year is the average of four replicates. The seven-year averages are also shown. An analysis of variance was run on the results obtained each year and on the combined data for seven years. Where significance was indicated by the F-test, the least significant difference was also calculated.

The results of the soil analyses are shown in Table 3. Each value shown is the average from the four replicates. Calcium is not reported because the calcium content exceeded the standards used in the Soil Testing Laboratory.

TABLE 1.—YIELD OF MARKETABLE TOMATOES IN PHOSPHORUS FERTILIZER TEST. (POUNDS PER 0.01 ACRE PLOT)

Treatment	Year							
	1949	1950	1951	1952	1953	1954	1955	Avg.
Check	81.8	45.9	113.7	91.1	94.5	113.1	159.4	100.0
Low	106.5	64.0	153.8	118.8	125.7	193.1	265.7	146.5
Medium	109.6	87.0	144.8	102.1	122.3	233.9	253.5	149.0
High	124.7	96.7	141.1	98.2	103.8	199.4	281.1	149.3
L.S.D. .05	26.4	23.4	34.4	23.3	13.0	45.0	55.4	20.2
.01	37.1	32.7			18.3	63.2	77.7	27.7

TABLE 2.—Yield of Tomatoes of All Grades in Phosphorus Fertilizer Test. (pounds per 0.01 acre plot)

Treatment	Year 1949	1950	1951	1952	1953	1954	1955	Avg.
Check	151.5	117.4	151.6	149.0	147.0	154.9	210.8	154.6
Low	184.0	148.8	242.8	207.9	236.7	286.4	386.3	241.8
Medium	183.5	218.0	246.4	214.4	239.9	334.5	395.3	261.7
High	216.3	226.4	252.1	211.1	215.3	301.0	430.9	264.8
L.S.D. .05	50.8	60.8	50.4	46.0	35.7	63.3	68.2	28.8
.01		85.3	70.7	64.6	50.3	88.8	95.5	39.4

TABLE 3.—Soil Test Results from Phosphate Fertilizer Test. 1954

Treatment	Pounds per acre P_2O_5	K_2O	MgO
Check	40	522	2613
Low	61	305	2630
Medium	70	268	2840
High	105	271	2630
L.S.D. 0.05	25	76	*
0.01	36	107	

*Analysis of variance inapplicable to these data.

The results of the tomato leaf analyses are shown in Table 4. Each value is the average of four replicates. Duplicate analyses were made on each sample. All the results are reported as percentages of dry weight.

DISCUSSION

Yields. The effects of the treatments observed in the field were reflected in the yields. The consistently poor yields from the check plots were added evidence of phosphorus deficiency. Although the high phosphate plots always looked best early in the season, they frequently produced less fruit than plots to which less phosphate was applied and on which the plants were slower to develop.

A significant increase in yield of both marketable and total fruit was obtained from the application of phosphate in each of the seven years. This was very different from the results obtained in the potato experiment (3). The most significant response was not to the same rate of application every year. Every year the largest difference in yield between two successive treatments was between the check and low phosphate. Additional increases were obtained with the medium rate of application in some years and not in others. In only one year was this

TABLE 4.—Composition of Tomato Leaves at Harvest.
(percent dry weight)

Year	Phosphorus Treatment	N	P	K	Ca	Mg	N/P
1952	Check	3.79	0.19	2.6	2.6	0.57	19.8
	Low	3.72	0.27	2.7	2.6	0.57	13.8
	Medium	3.67	0.29	2.6	2.6	0.53	12.5
	High	3.64	0.32	2.5	2.6	0.54	11.3
	L.S.D. 0.05	NS	0.05	NS	NS	NS	3.3
	0.01		0.07				4.6
	0.001		0.09				NS
1953	Check	3.69	0.21	2.7	3.5	0.72	17.6
	Low	3.12	0.27	2.7	3.8	0.66	11.6
	Medium	2.90	0.28	2.5	3.8	0.72	10.3
	High	2.89	0.31	2.5	3.8	0.69	9.4
	L.S.D. 0.05	0.29	0.02	NS	NS	NS	1.8
	0.01	0.41	0.03				2.6
	0.001	0.61	0.04				3.9
1954	Check	4.58	0.26	4.1	1.5	0.46	17.6
	Low	3.98	0.29	3.3	2.0	0.41	13.9
	Medium	3.63	0.30	3.1	2.1	0.38	12.1
	High	4.02	0.34	3.1	2.0	0.42	11.9
	L.S.D. 0.05	0.56	0.04	0.8	NS	NS	1.8
	0.01	NS	NS	NS			2.5
	0.001						3.7
1955	Check	4.36	0.23	2.4	2.0	0.43	19.1
	Low	4.13	0.23	2.2	2.2	0.42	18.2
	Medium	4.15	0.25	2.2	2.2	0.41	16.5
	High	4.19	0.27	2.2	2.1	0.40	15.6
	L.S.D. 0.05	NS	0.03	NS	NS	NS	1.0
	0.01		NS				1.5
	0.001						2.1
Average	Check	4.10	0.22	3.0	2.4	0.54	18.4
	Low	3.74	0.26	2.8	2.6	0.51	14.3
	Medium	3.59	0.28	2.6	2.7	0.51	12.7
	High	3.69	0.31	2.6	2.6	0.51	11.9
	L.S.D. 0.05	0.21	0.05	NS	NS	NS	1.6
	0.01	NS	NS				2.3
	0.001						NS

increase significant and then only in total yield and not in the yield of marketable tomatoes. The high phosphate treatment produced more tomatoes than the medium in about half the years and less in as many years. In 1952 and 1953, the yields of marketable fruit from the high phosphate plots were significantly lower than those from the low phosphate plots. In both years the yields of marketable fruit were below the seven-year average, which can be seen in Table 1. There was no significant difference in yield among the seven year averages from the low, medium, and high phosphate plots and none in five of the seven years when considered separately. There was a very highly significant interaction between treatments and years.

The yields varied from year to year but the general trend was upward. The improved yields were the result of an improved overall program. In the first three years the nitrogen levels were too low to give maximum yields, as shown in the concurrent nitrogen experiment (2). In 1950, wilt reduced the yield of marketable fruit and starting in 1951 the Homestead tomato was planted in preference to the wilt-susceptible Grothen Globe. In 1952, severe virus infection caused the plants to lose vitality and only three pickings were obtained. The next year was wet and many plants were damaged by water. Both 1954 and 1955 were good growing seasons. The highest yield from any treatment in any year was from the high phosphate plot during the last year of the test.

The proportion of marketable fruit varied from year to year and among different treatments. For example, only 42 percent of the fruit from the high phosphate plots was marketable in 1952 but 65 percent was marketable in 1955. Over the seven years, the proportion of marketable fruit decreased on an average from 65 percent from the check to 56 percent from the high phosphate plots.

The proportion of cull fruit was not related directly to the phosphate treatments. Rots, insect damage, and rodent damage were all problems. In the majority of cases, these were most severe on the plants which produced the best vines, usually on the high phosphate plots. Virus diseases were most severe on these same plots, since the plants grew most rapidly here and were the first to be dragged by the tractor and the sprayer. As the plants became large, direct mechanical damage also was a problem. These hazards were reduced but not completely eliminated in 1954 and 1955 by the use of high clearance equipment.

The very low proportion of marketable fruit in 1950 showed the effect of fusarium wilt. After growing quite vigorously and setting a heavy crop, the vines went down quickly, losing their leaves and exposing the fruit to the hot spring sun. The major cause of culls in this season was sunburn.

Soil Analyses. Although soil samples were taken from these plots only one year, they show both the direct and an indirect effect of the application of phosphate. The phosphorus extractable with acid ammonium acetate was significantly greater on the phosphate treated plots than on the check. Furthermore, inspection of the data in Table 3 will show that the increase in the extractable phosphorus over the check was roughly proportional to the rates of application of phosphorus. This was quite unlike the yield, which reached a maximum in most years. The potash content of these samples was significantly lower where the phosphate had been applied. Comparison of the potash and phosphorus data suggests that this reduction in potash content was not a direct effect of the application of phosphate. Comparing the potash content of the soil with the yield data shows that there is a clear inverse relationship between the two. The application of phosphorus resulted in better utilization of the potassium. The amount of extractable potash in the check samples suggests that it had accumulated over several years. There was no difference in the magnesium content of the samples related to the treatments or the growth of the plants.

Leaf Analyses. The nitrogen content of the tomato leaf samples varied with treatment and from one year to another. In two of the four years it was significantly reduced by the application of phosphate. The difference in the four year average was also significant. Comparing the results in Table 4 with the yields shows that the nitrogen content of the leaves varied inversely with the yield. Attention has already been called to the nitrogen shortage in 1953 which was inferred from the results of a companion experiment. The nitrogen content of the leaves from the medium and high phosphate plots was lower than the nitrogen content of the leaves from the 240 pound nitrogen plots which produced the best yield in the nitrogen experiment (2), additional evidence that nitrogen was a limiting factor. This was the only year in which there was a very highly significant reduction in the nitrogen content of the leaves as a result of the application of phosphate. There was also a significant reduction in the nitrogen content of the leaves on the phosphate plots in 1954 but in that year the nitrogen content did not fall below that of the leaves in the companion experiment.

The phosphorus content of the tomato leaves increased with each increment of phosphorus applied to the soil, but the increase was not directly proportional to the rate of application. The increase was significant by the F-test in each of the four years. The degree of response varied from year to year, as shown by a significant year-treatment interaction. In the last year of the test, with adequate nitrogen and potash and favorable weather conditions, the plant had little opportunity to accumulate phosphorus. The average phosphorus level was not significantly different from one year to another in spite of the many changes in the growing conditions, suggesting that the phosphorus content of the leaves might be a useful measure of the adequacy of the phosphorus supply for tomatoes. Reviewing the data from the nitrogen experiment (2), at the high rates of nitrogen application phosphorus was becoming a limiting factor. The phosphorus content of the tomato leaves from the check plots was no lower in 1955, the last year of the test, than in 1952, the first year in which the leaves were analyzed, indicating that the phorphorus supply was not being depleted. The highest yields obtained from the check plots in any year were in 1955.

The potassium content of the tomato leaves varied significantly from one year to another, but only in 1954 was there a significant difference between treatments. The reduction of potassium concentration in the leaf with phosphate treatment was a function of the yield rather than bearing a direct relation to the rate of application of phosphorus. It was similar to the change in the soil potash found in the same season.

Neither the calcium nor the magnesium content of the tomato leaves was significantly affected by the rate of application of phosphorus.

The nitrogen-phorphorus ratio of the tomato leaves was the most sensitive measure of response to treatment. The reduction in this ratio resulting from the application of phosphorus was highly significant in all four years and was significant at the 0.001 level in three of the four years. Ratios greater than 13-1 were associated with phos-

phorus deficiency, as indicated by yields. Ratios less than 12-1 were associated with an excess of phosphorus, as indicated by yield, or with an inadequate nitrogen supply.

Calculations of the coefficients of variation showed that the composition of leaves on the replicate plots of the same treatment was less variable than the yield. This is quite reasonable, since the yield is affected by many circumstances such as fruit rot, insects, and loss of plants which have no influence on the leaves or roots of surviving plants.

CONCLUSIONS

The deep marl did not contain sufficient available phosphorus for maximum growth of tomatoes but released a small amount at a relatively constant rate year after year. The most efficient rate of application was 70-75 pounds of P_2O_5 per acre per year. Although the yields were somewhat lower on the plots receiving the highest rate of application of phosphorus in some years, this usually was the result of secondary effects of the treatment. Since the best yield ever obtained was from the high phosphate plots during the last year of the experiment, there is no evidence of an accumulation of harmful quantities of phosphorus.

The nitrogen, phosphorus, and potassium contents of the tomato leaves were all affected to some extent by the application of phosphate to the soil. The nitrogen content was decreased as the rate of application of phosphorus increased. This effect was most apparent in the season during which nitrogen was deficient. The potassium showed a similar inverse relationship to phosphate application but the change was significant in only one season. The phosphorus content of the tomato leaves was increased by each successive application of phosphorus. The application of phosphorus had no influence on the calcium or the magnesium content of the tomato leaves. The nitrogen-phosphorus ratio of the leaves was the best indicator of the adequacy of the phosphorus supply. A ratio of 12.5-1 is suggested as the optimum.

There were no foliage symptoms observed which could be used for diagnosing phosphorus deficiency. Although soil analysis showed a buildup of extractable phosphorus, the only safe guide to practice was that a marl containing 40 pounds of P_2O_5 per acre, as determined by acid ammonium acetate extraction, gave a profitable yield increase from the application of phosphate.

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Cultural Practices Useful In Growing Field Corn On South Florida Sandy Soils

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In 1956 there were 587,000 acres of field corn grown in Florida with an average yield of only 21 bushels per acre (2). Much higher yields are necessary before field corn can contribute greatly to the state's economy. In south Florida, many instances of corn yields above 100 bushels per acre have been recorded in experiments on both organic and sandy soils. At Plantation Field Laboratory, Fort Lauderdale, two crops per year have been grown successfully on Davie fine sand in each of the past four years.

EFFECT OF TIME OF PLANTING

At Fort Lauderdale, field corn planted in late September and early October matured grain successfully in January. Likewise, late January and early February plantings yielded well when harvested in June. The fall corn crop either has been planted under excessive moisture conditions or has had young corn seedlings subjected to periods of heavy rainfall after planting. On the other hand, plantings made in the January-February period have had a minimum of moisture available for seed germination and nutrient availability. Therefore, adequate control of soil moisture, for either fall or spring crops is a prerequisite to successful corn culture on the sandy soils of south Florida.

During the fall of 1953 a succession of corn plantings—Sept. 3, Sept. 22, and Nov. 3—was made following conventional soil preparation, i.e., plowing, disking and harrowing. Heavy rainfall during October destroyed the September plantings by flooding. The planting of November 3 failed to produce a satisfactory stand because soil preparation had so loosened the surface soil as to prevent upward movement of capillary moisture. Seed planted at depths of 1½ to 2 inches failed to germinate either rapidly or uniformly. During these plantings water tables were maintained by sub-irrigation at levels 24 inches below the soil surface. Failure of all these plantings to grow satisfactorily pointed to the necessity of investigating other tillage and planting methods for field corn grown on sandy soils.

PLANTING AND CULTIVATION PROCEDURES

The first successful planting of field corn at Plantation Laboratory was made Nov. 24, 1953. The seed was planted 1½-2 inches below the bottom of shallowly listed furrows. Loose dry surface sand was pushed

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aside and seed was placed in firm, damp soil. After the corn seedlings emerged, it was necessary to deepen the middles to provide aeration and protection against flooding. When the corn was 6 to 12 inches high, center furrows were deepened with higher bedding or ridging of the corn row. Several advantages seemed to accrue from this ridging. First, nutrients were thrown nearer the plant roots. Second, by improving soil drainage, oxygen conditions were more favorable for root growth. Third, alternating furrows and ridges reduced the amount of sand movement and consequent plant injury by wind. Fourth, loose surface soil near the base of the corn plants reduced weed competition (1).

To overcome certain difficulties incurred in deepening furrows in the row middles, it was later found advantageous to plant corn with row spacing alternating 30 and 42 inches wide. Furrows were deepened only in the 42-inch centers and fertilizer was sidedressed within the 30-inch spacing. Two rows 30 inches apart permitted easy passage of equipment wheels in the wider 42-inch beds or furrows. High clearance tractors and spray equipment were operated in these middles without damage to the growing crop.

EFFECT OF WATER TABLE LEVELS

On September 30, 1955, Corneli 54 hybrid corn was planted (3) in triplicate in a series of concrete lysimeter tanks with water table levels of 12, 24, and 36 inches. Each tank lysimeter (4½′ x 5′ x 9′) had an area of approximately 0.001 acre. Lodging was more severe in corn growth with the 12-inch water level than with the 24 and 36 inch levels. The yield of corn produced at the 36-inch level was 69 bushels per acre, significantly lower than that produced on either the 12-inch (88 bushels) or on the 24-inch table (91 bushels). Nematodes and frost damage materially reduced yields of both grain and fodder in all plots.

On February 2, 1956, after the soil had been fumigated, these tanks were replanted with the same corn hybrid but water levels were maintained at 18, 24, and 30 inches. The corn was harvested June 1. Grain yield averaged 101 bushels per acre from the 18-inch tanks, 102 bushels per acre from the 24-inch tanks and 83 bushels per acre from the 30-inch tanks. Calculated forage yields were 22.8 tons, 23.2 tons, and 19.9 tons, respectively. This corn was grown in an exceptionally dry season—a fact which might favor the higher water-table levels. Field practice might favor somewhat higher water tables early in the growth of the corn plant, with a gradual lowering of the table as the root system develops. These data indicate superiority of the 18 to 24-inch water tables, provided good plant stands are obtained.

Since corn planted according to conventional methods over a 24-inch water table did not germinate satisfactorily, and because heavy rains destroyed stands by flooding, other planting procedures were investigated. Tillage methods which utilized existing soil moisture to the best advantage and at the same time avoided undue hazard from excessive rainfall were required (see Figure 1).

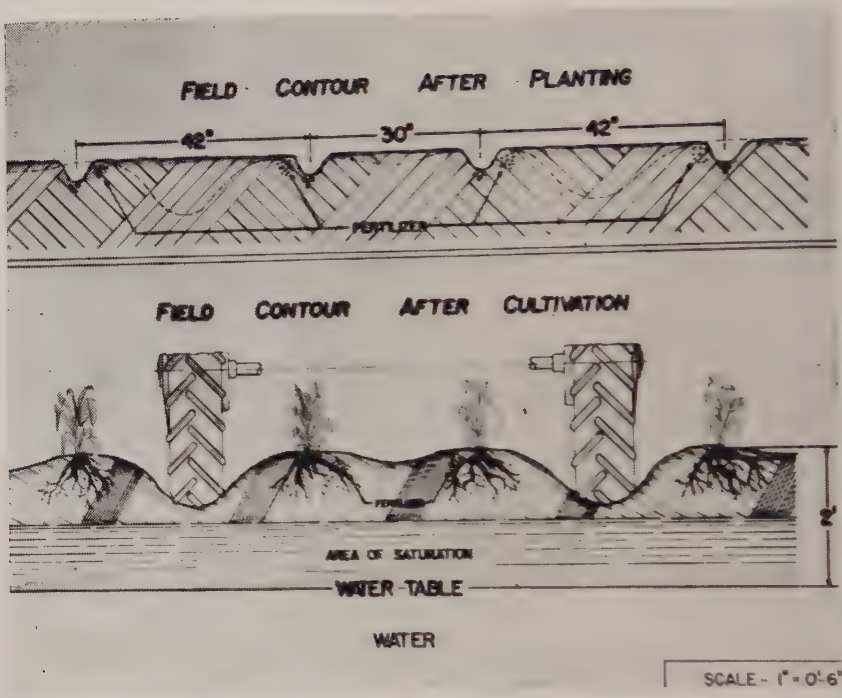

FIGURE 1.—Tillage practice suitable for growing corn on South Florida sandy soils. ABOVE—Field contour after planting; BELOW—Field contour after cultivation.

RATES OF PLANTING

In a rate of planting test of alternating 30- and 42-inch rows with spacings of two plants 24 and 18 inches apart in the row and single plants ever nine inches, lodging was more severe in the denser plantings, while least lodging occurred when hills of two plants were spaced two feet apart in the row. Differences in yield between the spacings were not significant. Therefore, two plants spaced every 18 to 24 inches in the row produced high yields of corn with a minimum of lodging.

TIMING AND PLACEMENT OF FERTILIZERS

In the production of 100 bushels of corn per acre, minimum quantities of fertilizers required are 150 pounds nitrogen, 40 pounds phosphorus, and 120 pounds potash. At planting time 600 to 800 pounds per acre of an 8-8-8-1 (Cu)-1 (Mn) can be applied near the corn row in the 42-inch middles. Sidedress applications of nitrate of potash (15-0-14) or similar fertilizer can be applied later in the 30-inch middles. Frequency and quantity of rainfall will determine the quantity and number of sidedressings required. Liming of soils, when indicated as necessary by soil tests, can best be done by broad-

casting dolomite or calcic limestone prior to disking and harrowing. Several sandy fields in the Fort Lauderdale area appear to have responded in higher corn yields to applications of calcic and dolomitic limestone. The kind and quantity of lime to be applied should be determined by soil test.

IRRIGATION TO REDUCE FROST HAZARD

In both the January and the September corn plantings there is an element of danger from frost injury at Fort Lauderdale. During the past two years efforts to reduce the frost hazard by irrigation have been successful. Deepened furrows between the bedded corn rows allowed warm canal water to be pumped into the corn field on cold nights without noticeable root damage. On frosty mornings the water vapor from warm canal water condensed to form a fog blanket which moved slowly over the corn field, preventing frost from injuring the corn plants. Corn on parts of the field north of the flooded rows and beyond canal protection was injured by frost, while corn within the fogged area remained undamaged.

INSECT AND DISEASE CONTROL

Successful field corn production is not possible without an intelligent program for the control of certain pests. Wireworms have proven devastating to young corn seedlings, particularly on land previously used for sod crops. Aldrin applied in broadcast fertilizer mixtures and disked in immediately, has given satisfactory control (1). Corn budworms, or fall army worms required more intensive control than any of the foliar insects. Spraying the growing plant with DDT, chlordane, or parathion, should be done as often as necessary to effect control.

Ear worms attack field corn but no insecticide-control measure appears justified. Tropical varieties and certain breeding lines produced from tropical varieties have a degree of resistance to this pest. Continued breeding for resistance offers the most practical measure of control.

Leaf diseases are prevalent in many varieties of field corn. Many tropical varieties, however, have a high degree of resistance. Continued breeding for resistance appears more promising for field corn than use of fungicidal sprays.

SUMMARY

Two crops per year of high-yielding field corn were grown successfully on the sandy soils of the coastal regions of south Florida. Intensive water control, a high level of soil nutrients, adaptable corn varieties, effective insect control measures, and tillage and planting procedures suitable for high plant populations were used for 100-bushel yields. A method of planting corn in alternating 30- and 42-inch rows with a population of 14,000 - 16,000 plants per acre is described. Flat cultivation at planting time, with subsequent bedding, proved successful in reducing wind, drought, and flood hazards.

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Effects Of Breaking Hardpan And Deep Plowing On Potato Yields

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INTRODUCTION

Smooth land is a prerequisite to successful and efficient drainage and irrigation by the water furrow method which is used in the Hastings area. The importance and value of land leveling for increased potato production has become increasingly more apparent during the past four or five years (3), Farmers have done more land leveling in the Hastings area since a Soil Conservation Service was established in St. Johns County in March, 1956 because this provided technicians for soil surveying, planning, staking and checking the completed work.

The leveling operation consists of cutting off the ridges, filling in the low spots and grading the field to a uniform slope, usually between one and four inches per 100 feet. The ridges and high areas in fields are frequently Leon soils and vary in size from small spots to several acres.

Leon soils are underlain with an organic hardpan which is usually quite impervious, thus preventing the capillary rise of moisture from the underlying saturated sand during furrow irrigation and retarding the downward percolation of moisture after heavy rains. The hardpan is usually between two and 12 inches thick and occurs between 14 and 30 inches in the profile (1,2). In 1917, Taylor, et al. (4) suggested that Leon soils might be used for potatoes if the hardpan layer were broken up by deep subsoiling or by blasting, thus permitting moisture to rise. However, Leon soils have been used without special hardpan treatment for Irish potato production in the Hastings area, but are not considered as productive as non-hardpan soils such as Bladen, Portsmouth, Rutlege and Scranton.

The organic hardpan or stained layer underlying other soils does not appear to impede soil moisture movement as does the cemented hardpan of Leon soils. An organic hardpan or stained layer occurs between 30 and 42 inches in the Immokalee, between 18 and 24 inches in the St. Johns, between 42 and 60 inches in the Pomello and above 14 inches in the Ona profiles (2).

The purpose of this study was to determine the effects of breaking the organic hardpan under Leon soils and of deep plowing on potato yields and net returns.

METHODS AND MATERIALS

During 1954 and 1955, land at the Potato Investigations Laboratory was leveled to a uniform slope of about two inches in a distance of 100 feet. A heavy track-tractor equipped with a bulldozer blade was

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used for pushing aside the top eight inches of dark soil, breaking up the hardpan under Leon "white caps," cutting off the ridges, filling in the low spots and replacing the topsoil. The final leveling was completed with a landplane pulled by a farm tractor.

One bed, 16 rows x 285 feet, of land which had been leveled in August, 1955 and an adjacent, undisturbed bed, 16 rows x 270 feet, were used in this study. In January, 1956 a 4 x 4 latin square experiment was set up in each of these beds. The areas had been limed after leveling with one ton per acre of dolomite to raise the soil pH to about 5.5. Potatoes were planted on January 12 in eight rows of each bed, using 2,500 pounds per acre of seed and were harvested 108 days later. The fertilizer treatments included the following pounds per acre of 6-8-8: (1) 2,500 at planting in bands; (2) "1" plus 500 sidedressed at 40 days after planting; (3) "2" plus 500 sidedressed at 50 days; and (4) "3" plus 500 sidedressed at 60 days. Artesian water was maintained in irrigation furrows adjacent to the plots from time of planting until one week before harvest.

Rye was planted as a winter cover crop in the remaining eight rows of the leveled bed and native crabgrass and weeds were allowed to grow in the remaining eight rows of the undisturbed bed. In October, 1956 these eight rows in the undisturbed area were plowed to a depth of 15 inches with a heavy three-disk plow attached to a "300" International Farmall tractor. The brown organic hardpan was cut and thrown to the surface in some areas where the hardpan occurred less than 15 inches from the surface. The soil was disced and smoothed with a land plane.

On January 24, 1957 the two 16-row beds were planted alternately with two rows of Sebago and two rows of Red Pontiac potato seed at eight inch spacings, equivalent to 2,450 pounds per acre, and fertilized with 2,437 pounds per acre of 7-9-9. Potatoes were harvested 95 days after planting.

RESULTS AND DISCUSSION

Soil Tests.—Soil pH and extractable nutrients found in two pulverized Leon hardpan samples and two topsoil samples taken near the experimental area are given in Table 1. Although the nutritional content of the two hardpan samples varied considerably, it is apparent that breaking up the hardpan and mixing it with the topsoil does provide additional nutrients for the potato crop.

Potato Yields in Area Leveled in 1954.—The three year average potato yield in areas where the organic hardpan had been broken and the land surface leveled in 1954 was 278.7 hundred-pounds per acre, as is shown in Table 2. In contrast, an adjacent undisturbed area used in entomological studies yielded 132.1 and 170.9 hundred-pounds per acre in 1953 and 1954, respectively. The potato yields and net returns for Sebago potatoes grown in the Hastings area in 1954, 1955, 1956 and 1957 are given in Table 3.

1956 Potato Yields in Area Leveled in 1955.—The total yield in the leveled area was 338.1 hundred-pounds per acre and in the undisturbed area was 314.9 as given in Table 4. The potato tubers grown in the leveled area were of better quality than those grown in

TABLE 1.—Soil pH and Extractable Nutrients in Four Leon Sandy Soil Samples Collected Near Hastings, Florida and Analyzed by the Soils Testing Laboratory, Gainesville.

Sample Number	Description	Soil pH	Extractable Lbs./A[1] Ca	MgO	P_2O_5	K_2O
A	Hardpan	4.7	112	83	80	118
B	Hardpan	4.6	56	115	9	11
C	0-6"	5.3	477	117	14	22
D	0-6"	5.0	344	125	31	17

[1]Extracted with ammonium acetate solution, pH 4.8.

TABLE 2.—Potato Yields in Areas Where Organic Hardpan Was Broken With Bulldozer Blade and the Land Surface Leveled in August 1954.

Year	Potato Variety	Cwt./A[1] U.S. 1A	U.S. 1B	Total
1955	Sebago	263.9	20.9	284.8
1956	Sebago	299.8	14.1	313.9
1957	Red Pontiac	210.8	26.4	237.2
	Average	258.2	20.5	278.7

[1]Based on yields of 12 plots, each 1 row x 25 feet in 1955; 12 plots, each 1 row x 14 feet in 1956, and; 4 plots, each 2 rows x 14 feet in 1957.

TABLE 3.—Potato Yields in Hastings, Florida Area.

Year	Total Yield,[1] Cwt./A	Net Returns,[2] $/A
1954	186	119.37
1955	159	206.77
1956	168	191.33
1957	135	—80.98
Average	162	109.12

[1]Based on values reported for 1954, 1955, 1956 and 1957 in Marketing Florida Potatoes, U.S.D.A. Agr. Mktg. Ser.

[2]Based on values reported for 1954, 1955, 1956 and estimates for 1957 by Donald L. Brooke in Fla. Agr. Exp. Sta. Mimeo Rpts.

the undisturbed area, which produced some tubers with scurf, "growth cracks" and corky ringspot. The calculated net returns were $173 more in the leveled area than in the undisturbed area. About half of this increase was due to the better quality of the crop. The other half was due to the increase in yield of 23 hundred-pounds per acre in the leveled area. Yields were not increased significantly by side-dressing in either the leveled or undisturbed areas.

TABLE 4.—Effects of Breaking Organic Hardpan in 1955 and Fertilizer Rates on Yields and Returns of Sebago Potatoes in 1956.

6-8-8 Fertilizer, Lbs./A	Total Yield,[1] Cwt./A	Costs/A		Calculated Returns/A	
		Growing[2]	Harvesting[3]	Gross[4]	Net
Hardpan Broken and Area Leveled					
2,500	332.1	$286	$332	$1,156	$538
3,000	342.9	299	343	1,180	538
3,500	336.0	311	336	1,146	499
4,000	341.1	324	341	1,198	533
Average	338.1	305	338	1,170	527
L.S.D. .05	28.5				
L.S.D. .01	43.1				
Undisturbed Area					
2,500	312.8	286	313	992	393
3,000	293.5	299	294	900	307
3,500	329.5	311	330	1,007	366
4,000	323.7	324	324	999	351
Average	314.9	305	315	974	354
L.S.D. .05	26.0				
L.S.D. .01	29.3				

[1]Yields calculated from 2 rows x 50 feet, replicated 4 times.

[2]Includes the following costs: seed, $3.40 cwt.; grading and sorting seed, $0.24 cwt.; fertilizer $2.56/cwt.; and all other growing costs, $132.57 A as reported for 1956 by Donald L. Brooke in Fla. Agr. Exp. Sta. Mimeo Rpt. 57-6, 1957.

[3]Total harvesting costs estimated at $1.00 cwt. for digging, picking labor, grading, packing, containers, hauling and selling commission.

[4]Returns of $4.42/cwt. for U.S. 1A and $2.24 cwt. for U.S. 1B potatoes based on average of daily quotations as reported by H. S. Stiles in Marketing Florida Potatoes, U.S.D.A. Agr. Mktg. Ser., p. 7, 1956 and $1.65 for Utilities based on sales by the Potato Investigations Laboratory.

The cost of breaking the hardpan and leveling the land depends on a number of factors, the principal ones being the cubic yards of soil moved, the type of equipment used, and the skill of the operator. The cost per operating hour for a track-tractor equipped with a bull-dozer blade or pulling a carryall ranges from about $8 to $20, depending on the size of the tractor. The average cost of breaking the hardpan and leveling the land at the Potato Investigations Laboratory was about $150. The cost was less than the increased net returns from potatoes in the leveled area in 1956.

1957 Potato Yields in Area Leveled in 1955 and in Area Deep Plowed in 1956.—Red Pontiac potato yields of 284.2, 269.5, 261.8 and 207.0 hundred-pounds per acre were obtained in the deep plowed area, leveled area where rye had been planted in 1956, undisturbed area and leveled area where potatoes had been planted in 1956, respectively, as given in Table 5. Yield differences between the deep plowed area and the leveled area where potatoes had been planted in 1956 were significant at the one percent level. Also, rye significantly increased the yield in the leveled area compared to potatoes.

TABLE 5.—Effects of Breaking Organic Hardpan in 1955 and Deep Plowing in 1956 on Yields and Returns of Potatoes in 1957.

Land Preparation	Previous Crop	Total Yield,[1] Cwt./A	Costs/A		Calculated Returns/A	
			Growing[2]	Harvesting[3]	Gross[4]	Net
Sebago Potatoes						
Hardpan broken & area leveled	Rye	225.6	$281	$226	$444	$—63
	Potatoes	162.5	281	162	317	—126
	Average	194.0	281	194	380	—94
Deep Plowed	Fallow	246.2	281	246	465	—62
Undisturbed	Potatoes	256.5	281	256	487	—50
Average		222.7	281	222	428	—75
Red Pontiac Potatoes						
Hardpan broken & area leveled	Rye	269.5	281	270	528	—23
	Potatoes	207.0	281	207	399	—89
	Average	238.2	281	238	464	—56
Deep Plowed	Fallow	284.2	281	284	522	—43
Undisturbed	Potatoes	261.8	281	262	515	—28
Average		255.6	281	256	491	—46

[1]Yields calculated from 1 row x 14 feet, replicated 12 times.

[2]Includes the following costs: seed, $3.40/cwt.; grading and sorting seed, $0.24/cwt.; fertilizer, $2.59/cwt.; and all other growing costs, $128.82/A as estimated for 1957 by Donald L. Brooke to be published in Fla. Agr. Exp. Sta. Mimeo Rpt., 1958.

[3]Total harvesting costs estimated at $1.00/cwt. for digging, picking labor, grading, packing, containers, hauling and selling commission.

[4]Returns per hundred-weight from Sebago potatoes, $2.24 for U.S. 1A and $1.31 for U.S. 1B; from Red Pontiac potatoes, $2.19 for U.S. 1A and $1.89 for U.S. 1B as reported by H. S. Stiles in Marketing Florida Potatoes, U.S.D.A. Agr. Mktg. Ser., p. 7, 1957; and, from Sebago Utilities, $1.05 and from Red Pontiac Utilities, $0.99 based on sales by the Potato Investigations Laboratory.

Sebago potato yields of 256.5, 246.2, 225.6 and 162.5 hundred-pounds per acre were obtained in the undisturbed area, deep plowed area, leveled area where rye had been planted in 1956, and the leveled area where potatoes had been planted in 1956, respectively. Yields in plots where potatoes followed potatoes were significantly lower at the one percent level than yields of other treatments. Differences in yield between undisturbed and deep plowed areas were not significant at the five percent level.

The relatively higher yield in the undisturbed area in 1957 was a contrast to the results obtained in 1956. However, there is an explanation for the potato yields being higher in the undisturbed area than in other areas in 1957. Heavy rains late in the growing season resulted in plant root injury which appeared to be less extensive among potato plants growing in the undisturbed area than among those in the area where the hardpan had been broken and incorporated with the topsoil. Therefore, the plants in the undisturbed area continued to grow until harvest, thus allowing more time for tuber

growth and expansion. Potato plants in the area where the hardpan had been broken tended to wilt during the hot afternoons after the rains when the soil remained saturated. Under such conditions it appears probable that the reduced rates of water absorption resulted because of a deficiency of oxygen in the soil.

CONCLUSIONS

Breaking the organic hardpan under a Leon soil and incorporating it with the topsoil facilitated soil moisture movement after irrigation by the furrow method, increased soil moisture retention and provided additional nutrients for the potato crop. The cost of this special land preparation, about $150 per acre, was less than the increased value of the potato crop in 1956. The beneficial results were greater the first year after breaking the hardpan than in the second year. The organic hardpan will probably reform after several years.

The stirring and mixing of the hardpan appeared to increase the proportion of small to large pore spaces in the soil. This condition is desirable during periods of low rainfall but could be hazardous during periods of high rainfall. However, damage to plant roots in a saturated soil moisture condition after heavy rains can be minimized by carrying out certain cultural practices. Lowering the drainage or irrigation furrow, which is usually located every 16 rows, will result in lowering the water table.

Deep plowing increased Red Pontiac potato yields nine percent and decreased Sebago potato yields four percent.

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Comparative Accuracy Of Certain Open-Side And Open-End Fertilizer Sampling Tubes*

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Investigations under the general Fertilizer Control Research Project indicated that the official Florida sampling tool used in collection of control samples might be causing a negative bias in nitrogen recovery and a corresponding positive bias in certain other ingredients in incomplete mixtures deriving nitrogen largely from pelleted materials (1, 2). The Florida tube is a simple slotted open-side, closed-end tube ¾ inch outside diameter with 30 inch penetration depth.

To examine the source of bias, various sampling tools were devised and tested by sampling a 10-0-10 fertilizer made up from pelleted ammonium nitrate, fine crystal muriate of potash and builder's sand. The fertilizer was placed in a box 6 x 6 x 30 inches, over one end of which was clamped a section of standard 4-ply fertilizer bag through which the various tools could be inserted. The cover of the box was inset so that compaction pressure could be applied for certain tests.

A minimum of eight and a maximum of 24 replicate cores were drawn in various tests. Each core was individually put into solution, and the solution analyzed for ammoniacal nitrogen as a measure of pelleted ammonium nitrate and for chlorine as a measure of muriate of potash recovered for a given core. The fertilizer was placed in the box in four different ways:

1—Dry mixture in loose condition.
2—Dry mixture in compact condition.
3—Moist mixture in loose condition.
4—Moist mixture in compact condition.

Moisture was supplied to 3 and 4 by adding water to the builder's sand before mixing. This amount of moisture in the mixture was barely perceptible to the touch, but was enough to develop some adhesion of materials without making them sticky. Compacted mixtures removed after completion of a test were very friable.

The sample tubes tested were based on two principles. They were the open-side closed-end tubes represented by the official Florida tube, and open-end cone-shaped tubes developed by the writers. Tests with various tubes indicated four possible sources of bias in recovery of pelleted materials.

I—Disproportionate entry of fine materials as compared to pelleted materials in a loose dry mixture entering an open-side tube.

II—Segregation of Materials around the perimeter of a hole forced into mixtures by a solid penetrating point. The geometry of

*Contribution from the Florida Agricultural Experiment Station, Gainesville, Florida. Originally released as Mimeo 57-1, July 1956.

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particle size distribution would tend to give a disproportionately large amount of fines at the perimeter as a result of forcing back of larger particles.

III—Formation of a compression and shear zone ahead of a tube. The process tends to develop segregation to the extent that the compression cone most resistant to shearing differs from the composition of the mixture.

IV—The relation of curvature of the circumference of an open-end tube to the diameter of the larger pellets in the mixture. As greater curvature is introduced by decreasing diameter, the tendency for larger pellets to move out instead of in becomes greater.

The order of development of tubes resulted from the order of recognition of possible sources of bias. This explains the non-orthogonal nature of the tests. Statistical comparisons were made by using the average standard deviation of 4.34, and making comparisons individually to values obtained by the Florida tube for the comparable moisture and compaction status, based on the standard error for the least number of replicates in the pair of values being compared.

Data are summarized in Table 1. The individual standard deviations are included because they have certain indicative value over and above their use in determining significance.

Descriptive names and letters for the various tubes have the following meaning:

Official Florida—This is the tube exactly as used for the collection of official samples.

Florida F—The official tube with a ½ inch fin welded the length of the tube on one side of the slot so as to give a deeper "bite" as the tube is turned in filling.

Florida PDF—The official tube with longer and sharper point and fitted with a finned sleeve thus making a double wall tube that would permit closure during penetration and withdrawal. The long point was intended to reduce the compression cone, the fin to give deeper "bite," and the closure system to prevent rakeoff of surface pellets during withdrawal.

VM—This refers to the open-end cone principle embodied in a series of tubes. The tube was constructed of stainless steel sheet welded into a cone 1⅛ inch diameter at the large end and decreasing in diameter at ¼ inch per foot toward the cutting or insertion end. The associated figure in inches refers to the insertion depth measured from the large end, after allowing 2¼ inches projection for a handle.

VM 20" S—Cut at 45° slant with inside diameter of 0.60" at cutting end.

VM 15"—Cut vertical. 0.75" inside diameter.

VM 15"SC—Cut at 78° slant. 0.75" inside diameter except the heel of slant depressed to reduce diameter to 0.63" and provide additional constriction at the opening into the tube. It was intended that the long point of the slant would separate the mixture without bias before a pressure cone developed, and that the depressed heel would allow rapid release of pressure within the tube end to aid unbiased entry.

TABLE 1.—Percentage Recovery of Nitrogen from 10-0-10 Made up From Pelleted Ammonium Nitrate, Fine Crystal Muriate of Potash and Builder's Sand.

Tube Type	No. of Samples Drawn	Standard Deviation (Av. 4.34)	Percentage Recovery of Nitrogen	Statistical Significance over Off. Florida Tube
Dry Mixture in Loose Condition				
Off. Florida	16	6.02	90.8	
VM 20" S	8	3.36	93.4	No
VM 15"	8	3.29	96.7	Yes (.01)
VM 15" SC	16	6.45	94.6	Yes (.01)
VM 15" C	8	2.97	91.8	No
Dry Mixture in Compact Condition				
Off. Florida	24	4.40	90.2	
Florida F	8	3.21	90.3	No
Florida PDF	8	5.47	87.2	No
VM 15"	9	3.60	94.8	Yes (.05)
VM 15" SC	16	7.71	95.8	Yes (.01)
VM 15" C	8	2.61	90.3	No
VM 10	8	6.83	100.9	Yes (.01)
Moist Mixture (0.44% water) in Loose Condition				
Off. Florida	24	5.78	97.2*	
Florida F	8	3.64	95.4	No
VM 20" S	16	2.81	95.6	No
VM 15"	8	2.59	97.1	No
Moist Mixture (0.44% water) in Compact Condition				
Off. Florida	18	5.38	93.2*	
VM 15"	16	2.79	97.7	Yes (.01)
VM 15" SC	22	4.79	97.6	Yes (.01)
VM 10" C	8	4.20	94.1	No
VM 10" B	8	3.24	96.5	No

*Official Florida tube gave significantly greater recovery (.01) from moist mixtures than from dry mixtures under similar compaction.

Vm 15"C—Vertical cut but constricted perimeter to give 0.65" inside diameter of cutting edge.
VM 10"—Cut vertical. 0.85" inside diameter.
VM 10"C—Constricted like *VM 15"C* to give 0.77" inside diameter.
VM 10"B—Cut vertical with ring inserted to give blunt end with 0.69" inside diameter and marked constriction.

The Florida type tubes were inserted with gradual even pressure in inverted position, and then turned to place the slots upright for withdrawal. The VM type tubes did not obtain the amount of sample to be expected when used with gradual pressure. Driving these tubes with sharp blows with a light ballpeen hammer proved to be the best procedure. This took advantage of the inertia of the material to move it into the tube with least bias.

Data in Table 1, fourth column, show first that the Florida tube introduced a definite negative bias in recovery of pelleted ammonium nitrate in dry mixtures. Modifying the Florida tube gave no improvement. The best recovery with this tube was from moist loose mixtures where dry segregation of fines, of Type I bias did not occur, and where there was not sufficient resistance to penetration to develop much segregation of Type II. VM tubes did not improve on accuracy with this mixture. This agrees with results from complete mixtures sampled under the general Fertilizer Control Research Project.

The VM tubes improved accuracy in practically all instances where the Florida tube was grossly in error. The 15 inch tube gave significantly increased recovery of ammonium nitrate in all instances, except when a tube with constriction around the entire perimeter was used; or with the loose moist mixture where the Florida tube itself gave little bias. The improved accuracy amounted to reduction of the bias by 50 to 60 percent. Apparently the slant cut and partial constriction of VM 15" SC is not necessary. A tube of greater diameter would reduce bias still more, and such a tube may be practical provided damage to the bag is not a limiting factor. Constriction around the complete circumference of the tube appears to be undesirable, probably because of greater development of a compression cone.

Figure 1 shows the type of positive bias usually occurring for muriate of potash when a negative bias of pelleted ammonium nitrate exists. This is a summary of all samples analyzed for Table 1. If the pelleted nitrogen does not enter the tube in proper proportion, then it must be substituted with fines to take its place. The degree to

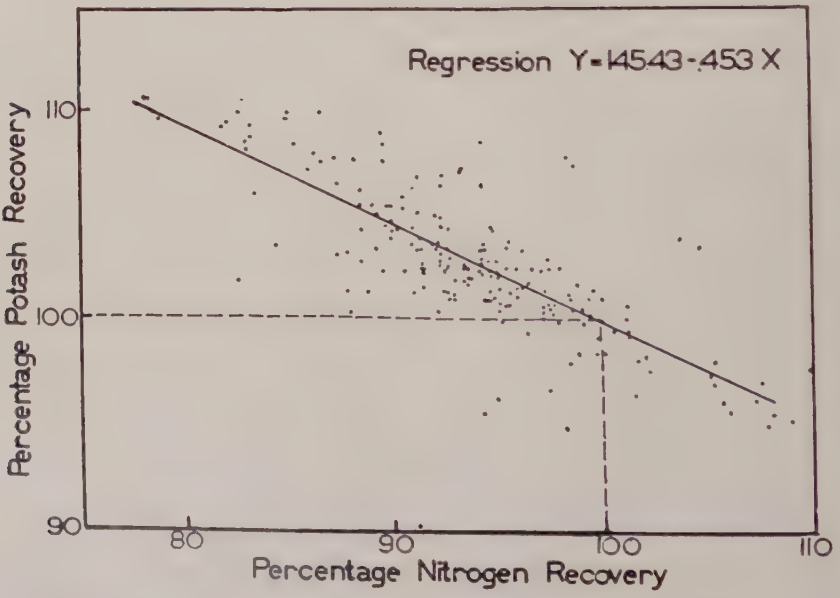

Figure 1. Inverse Correlation Between Recovery of Nitrogen from Pelleted Ammonium Nitrate and potash from Fine Crystal Muriate.

which this negative correlation occurred is shown by the graph. The fact that the regression line passes through the 100 percent recovery intersection indicates the accuracy of the investigational procedure.

The Florida tube collects from 100 to 150 grams of sample per probe, while the VM15" tube collects 100 to 130 grams per probe depending on dryness and compaction of mixtures. The best construction for the VM15" tube and protective driving head to withstand field usage is yet to be decided. The head used for the laboratory tests was a 2 x 2 inch piece of oak flooring to the reverse side of which was nailed a rubber stopper of proper size to center it and hold it to the tube end. There was no evidence of clinging or compaction in the cone shaped tube. A simple cylindrical tube was not considered because experience with soil tubes indicates that jamming sufficient to increase the compression cone would result even if constriction at the cutting edge were included.

Depth of penetration of a tube is important in obtaining a long cross section of material, and to properly sample bagged mixtures without consistently introducing the bias resulting from segregation within bags. The official tool with 30 inch penetration is intended to be used diagonally from corner to corner of a sack lying on its side. The principle is sound, but in practice the most biased areas probably lies next to the sack wall and may not be properly sampled because of danger of double puncture of the bag at extreme penetration. A substitute would be ½ penetration, assuming sacks are sampled from either end with equal frequency. This would eliminate one serious objection to the VM sampler—the large diameter and resulting bag damage necessary to give penetration depth equal to the Florida tube, yet retain the cone shape essential to free entry of the sample. A sampler of 15 inches penetration depth appears to be within reason.

The primary contribution of these tests is the principle of the cone-shaped open-end tube, and the use of sharp, light driving blows rather than pressure as the method of insertion. The value of moisture or a similar factor to increase cohesion is indicated. The most promising tube to compare to the official Florida tube would be VM15" without slant or constriction.

In using this tube it is necessary first to make a hole in the bag with a pointed probe so that the point of the tube can be inserted without carrying a wedge of paper and restricting freedom of entry of the sample. The weight of the driving hammer will be determined by the weight of the tube plus head, and by resistance to penetration encountered in routing use. Its weight should be such that a sharp blow will move the tube between one-half and one inch.

Further testing of tubes of the VM 15" type, recommended above has been carried out under actual working conditions since completion of the above investigation, and are being published elsewhere (3, 4).

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Effect of Subsoil Type and pH on Growth and Macronutrient Level of Leaf Tissue of Pineapple Orange Seedlings

G. K. Rasmussen and P. F. Smith[1]

INTRODUCTION

One of the most important chemical qualities of a soil is its pH. Soil acidity and alkalinity in relation to nutrient availability and citrus growth have been widely discussed (1, 4, 7, 8). However, no studies in which subsoils were used as substrates have been reported. Since citrus roots are found very deep in the subsoil, it was decided to investigate the effects of subsoil type and pH on the growth rate and the mineral-nutrient status of citrus seedlings as indicated by macronutrient levels in leaf tissue of Pineapple orange seedlings.

Good growth of citrus has been found in solution and sand cultures over a fairly wide range of pH (3, 4), but pH near 4 and below resulted in stunted growth (6). Aldrich et al. (1) recently found a correlation between soil pH and growth of seedlings; as the soil became more acid (pH 8 to 4) growth decreased. However, they used sulfur to lower the pH and it is not clear whether the retarding effect was SO_4 toxicity or from other factors associated with the pH change.

In Florida most of the citrus subsoils are naturally acidic and usually become more so under the cultural practices followed in fertilization and pest control. No information is available as to a desirable pH level to be maintained in the subsoil of any of the common soil types used for citrus. For this reason 3 subsoil types representing the major citrus soils of the ridge area were adjusted to several pH levels and used as substrates for the growth of Pineapple orange seedlings.

METHODS AND MATERIALS

Batches of matched virgin and grove subsoils were collected from 4 locations by combining numerous cores taken from 6- to 20-inch depths with 3-inch soil tubes. These represented 3 soil types as follows:

(1) Eustis fine sand from a 14-year-old orange grove and an adjacent virgin site.
(2) Orlando fine sand from a 35-year-old orange grove and an adjacent site.
(3) Lakeland fine sand (no. 1) from a 17-year-old orange grove and an adjacent site.
(4) Lakeland fine sand (no. 2) from an 80-year-old seedling orange grove known to contain excessively high Cu in the top 6 inches and an adjacent virgin site.

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Each batch of soil was screened and carefully mixed to homogenize it; then one portion was treated with M H_2SO_4 and another with M $CaCl_2$ solution to saturate the exchange capacity with H and Ca, respectively. These were repeatedly leached with rainwater until they were essentially free of residual salts. The H-saturated soils then showed a pH near 4 and the Ca-saturated a pH near 7. The H-treated and Ca-treated subsoils were combined and mixed in proper proportions to give 6-kg lots each at 5 pH levels: 4.0, 4.3, 4.6, 5.0, and 6.0.

Two kg of each soil mixture was placed in a new clay pot and planted with 2 Pineapple orange seedlings (10-cm height) on May 7, 1956. The pots were randomized in split-plot design using grove-virgin pairs in 3 replications on the greenhouse bench.

On Fridays 100 ml of a complete nutrient solution containing an 80:20 ratio of NO_3 and NH_4 and adjusted to the same pH as the subsoil with H_2SO_4, was applied. This combination of nitrogen sources minimizes pH drift of growth substrates. The seedlings were watered uniformly 2 or 3 times a week with excess rainwater and after each watering, water stood in the saucer under each pot. Periodically these drainings were poured out to prevent excessive salt accumulation. After 5 months the seedlings were harvested, and the dry weights of tops and roots were determined.

While all pots were watered uniformly to keep the most sandy ones moist, it became apparent that the Eustis f.s. subsoil cultures tended to be waterlogged because of its higher clay content. It seemed possible that excess moisture might be a factor in the poorer growth in that soil. Consequently, a follow-up experiment using some of the same pots of soil but with controlled soil moisture was carried out in 1957. Three replications of Eustis f. s., Orlando f.s., and Lakeland f.s. virgin-soil types were used, since the previous study had showed practically no difference between any of the grove and virgin samples or between the 2 Lakeland f.s. sources.

Triplicate pots were planted, as indicated for the 1956 experiments, on April 11, 1957. In this experiment the pots were watered differentially 3 times a week. Prior to planting of the seedlings, the amount of water necessary to reach field capacity for each soil was determined. Thereafter, the pots were weighed and water was added until the weight of the soil plus the pot equaled the pre-determined weight. Thus, no leaching occurred and the soil was never saturated with water. The duration of this experiment was also 5 months, and the same dry-weight determinations were made as in the previous year.

The leaf concentrations of N, P, K, Ca, and Mg were determined at the end of the 1956 experiment and the K, Ca, and Mg at the end of the 1957 experiment by previously described methods (5).

RESULTS AND DISCUSSION

Effect of soil type and pH on growth. Very little difference in growth of the seedlings existed in the grove and virgin subsoils; therefore, the weights of the seedlings were combined and presented as means in table 1.

Growth was the best at pH 6.0 in all subsoil types in 1956. In 1957 growth was best at pH 5.0 in Eustis f.s. subsoil and at pH 6.0 in

TABLE 1.—Mean Dry Weights (gm per plant) of Pineapple Orange Seedlings Grown for 5 Months in Each of 2 Years & 3 Different Subsoil Types With pH Adjustment as Shown

pH		1956			1957		
Start	Finish	Tops	Roots	Total	Tops	Roots	Total
			Eustis fine sand subsoil				
4.0	4.0	1.17	0.73	1.90	2.76	2.83	5.59
4.3	4.2	1.50	1.27	2.77	2.67	3.67	6.34
4.6	4.5	1.73	1.07	2.80	3.80	4.10	7.90
5.0	4.8	2.37	1.30	4.03	3.97	4.17	8.14
6.0	6.1	3.07	2.00	5.07	3.70	3.57	7.27
			Lakeland fine sand subsoil				
4.0	4.1	2.13	1.15	3.53	2.97	2.87	5.84
4.3	4.3	2.66	1.50	4.03	2.97	3.30	6.27
4.6	4.7	2.84	1.72	4.56	3.20	3.37	6.57
5.0	5.0	2.53	1.75	4.28	3.43	3.53	6.96
6.0	5.8	2.55	2.25	4.80	4.07	3.30	7.37
			Orlando fine sand subsoil				
4.0	4.0	2.63	1.63	4.26	3.47	3.10	6.57
4.3	4.4	3.10	1.87	4.97	4.07	3.73	7.80
4.6	4.7	2.53	1.63	4.16	3.53	3.20	6.73
5.0	4.9	2.65	1.57	4.22	3.90	3.20	7.10
6.0	5.7	3.53	2.27	5.80	4.00	4.37	8.37
L.S.D. @ 19:1 between any 2 means		.39	.30	.32	.63	.54	.78

the other subsoil types. Growth was poorest at pH 4.0 in all subsoils both years. Low pH reduced growth most in Eustis, a clayey subsoil, and this reduction was particularly striking in the presence of excess moisture in 1956. The least growth response to pH was in the Orlando subsoil, which contained the most organic matter. In this subsoil growth decreased only slightly as the acidity increased. Good growth occurred at nearly all pH levels. Growth in Lakeland f.s. sources no. 1 and no. 2 did not differ materially; therefore, the seedling weights were combined and presented as means in tables 1 and 2. This extremely sandy subsoil was intermediate between the other two in its effect on growth in relation to pH. Growth was definitely depressed at pH 4.0 with only slight improvement from pH 4.3 to 6.0.

The data presented in table 2 are the means for all the pH levels for each soil type and the data for all soil types are combined for each pH to show the generalized effects of these factors on growth. Subsoil types did not show any appreciable differential effect on total growth of the orange seedlings when the moisture level was controlled (1957); however, under high moisture conditions there was greater inhibition of growth in the clayey Eustis subsoil than in the two sandy subsoils.

The overall effect of pH on growth of the seedlings shown in table 2 is intermediate between that in Eustis f.s. and that in Orlando f.s.

TABLE 2.—Main Effects of Subsoil Type and pH on the Mean Dry Weight (gm per plant) of 2 Crops of Pineapple Orange Seedlings Grown for 5-Month Periods in Each of 2 Years

Soil type or pH	1956			1957		
	Tops	Roots	Total	Tops	Roots	Total
Soil type:						
Eustis f.s.	1.88	1.36	3.24	3.31	3.67	6.98
Lakeland f.s.	2.68	1.67	4.35	3.33	3.67	7.00
Orlando f.s.	2.97	1.80	4.77	3.79	3.52	7.31
L.S.D. @ 19:1	.63	N.S.	1.00	.24	N.S.	N.S.
pH:						
4.0	1.28	2.05	3.30	2.93	3.07	6.00
4.3	1.61	2.55	4.16	3.57	3.23	6.80
4.6	1.63	2.65	4.27	3.56	3.40	6.96
5.0	1.58	2.65	4.27	3.63	3.77	7.40
6.0	2.07	3.01	5.05	4.41	3.92	8.33
L.S.D. @ 19:1	.30	.39	.55	.54	.63	.78

subsoil. Growth was best at pH 6.0, poorest at pH 4.0, and almost equal from pH 4.3 to 5.0.

The results indicate that apparently no deleterious change in Lakeland no. 2 subsoil had taken place over 80 years of citrus culture since young seedling growth was as good in it as in the young-grove and virgin Lakeland f.s. subsoils.

Under field conditions it is difficult, if not entirely impractical, to keep subsoil pH levels as high as 6; therefore, the best compromise for best growth appears to be keeping the subsoil pH above about 4.5. Field experiments (7) show that this can easily be accomplished through proper liming practice even when highly acidulating forms of nitrogen and a heavy-sulfur pest control program are used.

Effect of virgin and grove subsoils on growth and mineral status of orange seedlings. Results of the 1956 experiment indicated that there were practically no differences in growth or macronutrient contents of leaf tissue of the plants grown in virgin and grove subsoil samples (table 3). The only exception was that the Ca and Mg contents of leaves from seedlings grown in grove samples of Eustis f.s. subsoil were significantly less than the Ca and Mg levels of leaf tissue of seedlings grown in virgin Eustis f.s. subsoil. Thus it appears that virgin subsoils are not necessarily better for growth of citrus than grove soils.

Effect of soil type and pH on mineral status of orange seedlings. Subsoil type had no effect on the concentration of N, P, or K in leaf tissue in 1956 and no effect on K and Ca levels in 1957 under controlled moisture conditions. In 1956 Ca and Mg levels were significantly less in leaf tissue of seedlings grown in Eustis f.s. subsoil than that of seedlings grown in the other subsoil types. The Mg level of leaf tissue from seedlings grown in Orlando f.s. subsoil was significantly greater than that of seedlings grown in the other subsoil types in 1957 (table 4).

TABLE 3.—Effects of Grove and Virgin Subsoils on the Dry Weight (gm per plant) and the Mineral Content (percent of element in leaf dry matter) of Pineapple Orange Seedlings Grown for 5 Months in 1956

Soil type	Tops	Roots	Total	N	P	K	Ca	Mg
Eustis virgin	1.97	1.27	3.24	2.63	.14	1.95	1.39	.30
Eustis grove	1.79	1.44	3.23	2.57	.12	2.06	1.19	.26
Lakeland no. 1 virgin	2.62	1.80	4.42	2.54	.15	1.75	1.36	.33
Lakeland no. 1 grove	2.68	1.66	4.34	2.60	.16	1.83	1.36	.32
Lakeland no. 2 virgin	2.60	1.52	4.12	2.47	.15	1.72	1.45	.33
Lakeland no. 2 grove	2.80	1.66	4.46	2.37	.18	1.56	1.56	.34
Orlando virgin	2.79	1.68	4.47	2.52	.15	1.96	1.57	.33
Orlando grove	3.04	1.92	4.96	2.41	.17	1.70	1.52	.35
L.S.D. @ 19:1	.63	N.S.	.87	N.S.	N.S.	N.S.	.17	.03

TABLE 4.—Main Effects of Subsoil Type and pH on the Mineral Content (percent in dry leaves) of Pineapple Orange Seedlings Grown for 5-Month Periods in Each of 2 Years

Soil type or pH	1956					1957		
	N	P	K	Ca	Mg	K	Ca	Mg
Soil type:								
Eustis f.s.	2.60	.13	2.01	1.29	.28	1.96	1.88	.38
Lakeland f.s.	2.50	.16	1.72	1.44	.34	1.94	1.88	.38
Orlando f.s.	2.47	.16	1.83	1.55	.34	1.96	1.91	.42
L.S.D. @ 19:1	N.S.	N.S.	N.S.	.17	.03	N.S.	N.S.	.02
pH:								
4.0	2.50	.14	1.89	1.01	.27	2.08	1.59	.32
4.3	2.53	.16	1.79	1.39	.33	2.02	1.72	.38
4.6	2.47	.15	1.89	1.36	.31	1.93	1.85	.43
5.0	2.56	.16	1.80	1.55	.34	1.89	2.08	.44
6.0	2.50	.16	1.70	1.81	.37	1.84	2.19	.38
L.S. D. @ 19:1	N.S.	N.S.	N.S.	.17	.06	N.S.	.26	.06

The effect of excessive moisture on K, Ca, and Mg uptake is in harmony with the results of Arnon and Hoagland (2), who found that root growth and mineral absorption by crop plants were in direct relation to aeration. In the present study the levels of these 3 elements were higher in all cases in 1957 with controlled watering than in 1956 with high moisture.

The acidity of the subsoil had a significant effect on the Ca and Mg levels of leaf tissue of seedlings grown under both moisture conditions. Table 4 presents the average levels of each nutrient for all soil types. Ca and Mg levels of leaf tissue increased as the acidity decreased. A trend toward increased K absorption as acidity increased was evident both years. This trend was more definite under controlled moisture conditions.

Solution-culture studies (6) showed that Ca, Mg, and K absorption by Pineapple orange seedlings was inhibited by increasing H-ion

concentrations in nutrient-solution cultures. The opposite effect on K absorption in these soil cultures is most likely related to the increased Ca supply on the exchange complex as pH is increased: consequently, a K: Ca antagonism or base reciprocation results. Apparently under the conditions of the experiments, pH had no material effect on N and P absorption.

SUMMARY

In a pot study during 2 years 3 common citrus subsoils and corresponding virgin subsoils were adjusted to a range of pH values from 4.0 to 6.0 and orange seedlings were grown in them with a complete nutrient solution for a 5-month period each year. The first year all pots were given the same amount of water and were watered heavily. The second year the pots were watered individually and the soil was kept between field capacity and the wilting point at all times.

Best growth generally occurred in pH 6.0 cultures and poorest growth in pH 4.0 cultures. Low pH reduced growth most in Eustis, a clayey subsoil, particularly in the presence of excess moisture. The Orlando, a dilute organic subsoil, showed only a slightly downward gradient in growth from pH 6.0 to pH 4.0, with good growth in nearly all cases. The Lakeland, an extremely sandy subsoil, showed an intermediate effect on growth with a definite depression at pH 4.0 but only a slight improvement in growth above 4.3. The Orlando and Lakeland subsoils were not greatly affected by the moisture level.

No important difference between grove and virgin samples in relation to growth or nutrient absorption was found. Growth was as good in very old-grove subsoil as in virgin or young-grove subsoils.

The Ca concentration in leaf tissue increased as pH and K absorption decreased. The Mg concentration increased slightly as the pH increased. Soil types had no important effect on element absorption. The concentration of all elements was higher in leaf tissue when the moisture level was controlled.

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Root Growth Responses to Soil pH Adjustments Made With Carbonates of Calcium, Sodium or Potassium[1]

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Field observations on Hubam sweetclover in Florida pastures showed that this normally taprooted plant frequently failed to root deeply, even on well drained soils. Experiments by Blue (4) proved that a normal, deep taproot could be produced when lime was mixed throughout the soil profile. This paper reports the results of additional experiments on the effects of soil pH adjustments made with carbonates of calcium, sodium and potassium, and soil calcium levels on the development of roots by Hubam sweetclover and other selected plants.

The literature contains many reports of the effects of soil pH and calcium supply on plant growth and an excellent review of the more pertinent literature was made by Schmehl *et al* (9). Elsewhere in this volume is a symposium discussing many of the aspects of the liming problem. More specifically, the work of Bledsoe and Harris (3) in Florida has shown the need for calcium in the soil to be in direct contact with the peg for the development of the peanut fruit. Robertson *et al* (8) have increased the depth of penetration of corn roots by applications of lime to acid subsoils. The association of copper toxicity on old soils with low soil pH values (7, 10) and the subsequent emphasis on use of fertilizer materials, especially nitrogen sources, producing neutral or alkaline reactions has served to increase the need for further studies on the effects of soil pH and calcium on root development.

EXPERIMENTAL

The 0-4" horizon of a virgin Leon fine sand was used in these pot experiments. Preliminary laboratory tests were made to determine the amounts of Na_2CO_3, and $CaCO_3$ necessary to bring the soil to approximately the same pH. This could not be done on a simple equivalence basis because of difference in the relative activity of these three basic ions (11). Since root penetration rather than total plant growth was to be the major study, the top portions of each pot were limed and fertilized uniformly. It was felt that under these conditions the plants should be able to obtain all the nutrients required from the top portion of the pot and only the treatments of the bottom portion of the soil in the pot would influence root development there. The first two experiments were conducted using inoculated Hubam sweetclover, Floranna strain. Soil and fertilizer materials were thoroughly mixed before the soil was placed in the pot. Details of the treatments are reported in Table 1.

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TABLE 1.—Plan of Sweetclover Experiments.

Materials:	4 gallon glazed pots. Virgin Leon f.s. 0-4" depth.
Experiment 1.	(4 Replications)
	Top 2 gallons of soil in each pot mixed with 3½ gms. 0-10-20 and 17 gms. $CaCO_3$. Treatments of bottom 2 gallons of soil were as follows: 1. Mixed with 14 gms. Na_2CO_3 2. Mixed with 21 gms. K_2CO_3 3. Mixed with 56 gms. $CaSO_4 \cdot 2H_2O$ 4. Mixed with 17 gms. $CaCO_3$ 5. No treatment
Experiment 2.	(2 Replications)
	Top 1 gallon of soil in each pot mixed with 2½ gms. 0-10-20 and 8½ gms. $CaCO_3$ Second gallon of soil in each pot—no treatment. Bottom 2 gallons of soil treated with the same variations as in Experiment 1 above.
Planted:	January 7, 1957 to Floranna strain sweetclover.
Harvested:	March 26, 1957.

The third experiment was similar to the first except that nitrogen, as ammonium nitrate, was supplied to each pot as required. This third experiment included Coastal bermudagrass, Pensacola bahiagrass, pangolagrass, sunflowers, tomatoes, Okinawa peach cuttings and seedlings of grapefruit and sour orange. These plants were harvested after two months' growth, except for the peach and citrus plants which were grown for five months. This experiment was not replicated. A fourth experiment was designed to study the effect of Ca-Na ratios, at a constant soil pH, on root development. This last experiment was conducted in gallon cans containing a uniform surface soil and varying $CaCO_3$-Na_2CO_3 treatments of the subsoil.

The first two experiments were conducted entirely in the greenhouse, while the third was moved outside as soon as the plants became established. Moisture was maintained at near optimum levels in the first two experiments and no leaching took place. Excessive rains flooded the pots of the third experiment on several occasions and it became necessary to open the bottom drain holes and provide a continuous soil contact so that the excess moisture would drain off. The fourth experiment was conducted entirely out of doors and all cans contained drainage holes to permit loss of surplus rain water.

RESULTS

Average soil analyses taken from the pots at the time of harvest of the first experiment are given in Table 2. Actual differences between soil layers in the pot may have been even wider than indicated, since some difficulty was encountered in keeping the soil layers completely

separated when they were removed from the pots. Similar results were obtained in the second and third experiments. The average dry weight production of tops and roots in the first two experiments are given in Table 3. Chemical analyses of the aboveground portion of the plants in these same experiments are presented in Table 4. The tomato roots because the plants suffered from attacks of insects and blight and did not make a vigorous growth. The citrus seedlings and

TABLE 2.—Average Soil Analyses of Pots from First Experiment at Harvest

Subsoil Treatment	Pot Section	pH	Ca ppm	K ppm	Na ppm
Na_2CO_3	Top ½	6.56	518	13	62
	Bottom ½	6.64	203	28	414
K_2CO_3	Top ½	6.55	568	83	15
	Bottom ½	6.60	256	861	17
$CaSO_4$	Top ½	5.92	573	25	10
	Bottom ½	3.59	1013	23	10
$CaCO_3$	Top ½	6.19	582	17	12
	Bottom ½	6.21	524	12	12
Check	Top ½	5.92	483	14	12
	Bottom ½	4.36	524	12	12
(Virgin Soil		4.52	172	22	---)

TABLE 3.—Average Dry Weight Sweetclover Per Pot in Grams.

Treatment	Weight of Tops	Weight of Roots*		
	Experiment 1, Average of 4 pots			
		Top ¼		Botton ½
1. Na_2CO_3	20.73	38.99		0
2. K_2CO_3	19.92	35.13		0
3. $CaSO_4$	18.88	23.83		5.51
4. $CaCO_3$	28.84	19.60		16.73
5. Check	18.25	20.61		4.76
	Experiment 2, Average of 2 pots			
		Top ½	Middle ¼	Bottom ½
6. Na_2CO_3	16.06	29.17	3.92	0
7. K_2CO_3	18.01	15.72	6.66	0
8. $CaSO_4$	15.72	17.62	1.12	0.88
9. $CaCO_3$	15.94	12.13	2.81	5.63
10. Check	13.56	11.16	----	5.80**

*Roots were washed but still contained consideratble sand.
**Weight for bottom ¾ of pot.

average dry weight and root distribution of the plants in the third experiment are shown in Table 5. This average does not include the peaches were omitted because excessive root growth along the wall of the pot complicated the results. Exclusive of these factors, it may be said that the general root growth response of these last plant species was about the same as those shown in Table 5.

In the fourth experiment, the growth of roots at the wall of the can, coupled with the small total soil volume and regular leaching rains, obscured the results. Reduced root penetration could be detected in the soil treated with Na_2CO_3 along and in the first level containing the lowest $CaCO_3$ to Na_2CO_3 ratio. Other levels seemed to have developed almost equally in so far as root growth was concerned.

DISCUSSION

The failure of plant roots to penetrate the soil where the pH had been raised by sodium or potassium indicates that soil pH alone is not the principal factor in root penetration. The root development in the Na_2CO_3 treated soil shown in Table 5 was the result of roots of a single plant growing down the juncture between the wall of the

TABLE 4.—Sweetclover Composite Analyses of Above Ground Plant Tissue

Treatment	Per Cent in Oven Dry Tissue			
	Ca	K	Na	N
		(Experiment 1)		
1. Na_2CO_3	0.65	2.30	0.05	3.05
2. K_2CO_3	.61	3.03	.03	3.12
3. $CaSO_4$	.67	2.10	.03	2.85
4. $CaCO_3$	.99	1.98	.08	2.80
5. Check	.65	1.80	.03	3.05
		(Experiment 2)		
6. Na_2CO_3	.36	1.80	.08	3.08
7. K_2CO_3	.30	2.75	.03	2.96
8. $CaSO_4$	.61	1.60	.03	3.05
9. $CaCO_3$	1.01	1.60	.03	2.87
10. Check	.28	1.40	.03	2.36

TABLE 5.—Average Distribution of Roots from Several Plant Species in Third Experiment

Treatment	Average Root Distribution in gms/pot		
	Top ½	Botton ½	Total
Na_2CO_3	58.0	8.5	66.5
K_2CO_3	63.5	0.0	63.5
$CaSO_4$	46.5	32.0	78.5
$CaCO_3$	52.0	44.5	96.5
Check	39.0	30.0	69.0

pot and the soil and was not a true soil penetration. The development of roots along the side of the container became more pronounced with time and increased soil leaching, as evidenced by the results with peaches and citrus. Undoubtedly, root penetration at this point was a response to nutrients moving down from the surface layer of soil through an expansion crack. Growth here was favored by easy movement of nutrients from the upper layer of soil, better aeration and reduced resistance. Best root penetration was obtained in the limed soil as was expected. Some penetration was obtained in the check soil, pH 4.36, but soil treated with gypsum, pH 3.59, was usually penetrated to a greater extent than in the check.

It was noted that plants growing in pots containing Na_2CO_3 or K_2CO_3 in the subsoil wilted quickly and required more frequent watering than plants of the other treatments. These shallow-rooted plants were unable to take advantage of the water in the lower half of the pot. The advantages of deep-rooted plants especially in times of drought are obvious.

It has been observed that manganese and aluminum toxicity may become important factors in reducing plant growth (9). The selection of this particular soil with its low mineral reserves (6) greatly reduced the influence of these factors. In these experiments the added calcium from gypsum appeared to be of more benefit than the harm resulting from the increased hydrogen activity, as evidenced by a drop in pH from 4.36 to 3.59 when the calcium was supplied from this source. The type of response obtained indicates the need for calcium in the rooting zone for proper development of the root, just as it is needed for development of the peanut fruit (3). The direct effect of soil pH on root growth may be relatively minor as long as the calcium supply is adequate. Lime applications to certain organic soils frequently result in improved plant growth without appreciable changes in the soil pH. Within reasonable limits, pH responses exhibited by plants are probably more closely associated with indirect effects of pH on mobility and availability of other ions in the soil. The improved root growth obtained with $CaCO_3$ over $CaSO_4$ with a pH differential of more than 2.5 units may be an example of indirect effects of soil pH.

Cormack (5) found that root hair development and elongation is dependent on the gradual hardening and cementing of the outer pectic layer of elongating cell walls through incorporation of calcium to form calcium pectate. He reported that the growing cells in young root tips literally fell apart when calcium was absent or when they were exposed to the action of pectic enzymes. In the sodium and potassium treated soils in the first three experiments, numerous small brown rootlets were observed in contact with but not penetrating the soil treated with these materials. The relatively large quantities of these ions present in the soil (equivalence ratios of approximately 9 to 5 for Na or K to Ca) and their greater mobility probably interfered with the uptake of calcium to such an extent that the cementing layer of calcium pectate did not develop sufficiently for root penetration. Downward translocation of calcium to the root tips from the surface soil is known to be a rather limited process (1, 2) and in these experiments was obviously insufficient to overcome the reduced uptake at the root tip.

CONCLUSION

This paper presents limited data on the effects of soil calcium and pH adjustments made with Na, K and Ca on the development of the root systems of several plant species. The data show the importance of calcium in root development and indicate that the relative quantity of calcium present is more important than pH in root development. The presence of high ratios of Na or K to Ca appeared to be more detrimental to root development than the equivalent quantity of hydrogen in the light sandy soils.

The conditions of these exploratory experiments were rather drastic, hence, similar results were obtained for all plant species tested. Undoubtedly, some differences between species can be shown by improved techniques and more detailed experiments on intermediate Na-Ca or K-Ca ratios. The point of emphasis is that an adequate calcium supply is the first essential for proper root development. Many secondary advantages accrue from maintenance of a favorable soil pH but the substitution of Na or K for any considerable portion of the Ca required to maintain a favorable soil pH may have a more unfavorable effect on root development than the untreated acid soil.

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The Effect of Lime on Plant Growth and Recovery of Nitrogen From Anhydrous Ammonia, Urea and Ammonium Nitrate in Acid Sandy Soils.[1]

William G. Blue and Charles F. Eno[2]

Data from nitrogen source experiments have led to the frequently quoted statement that pound for pound, nitrogen from different sources gives similar results. This is frequently true, but there are a number of factors which may cause variations in response. Soil reaction, age of the plants, kind of plant, the concentration of nitrogen, the presence of other ions, and light all have been shown to influence the utilization of nitrogen. Soil reaction and certain aspects of nitrogen concentration seem to be most important in the problems encountered in this study.

Pirschle (7) showed that plants cannot obtain sufficient nitrogen from ammonium salts in an acid medium. He later showed (8) that nitrate can be utilized over a much wider pH range than ammonium salts and that for neither compound is there a single pH value at which all plants make optimum growth. Tiedjens and Robbins (10) found that peach and apple tree seedlings could absorb and assimilate sufficient nitrogen from ammonium salts only in a pH range of from 7.0 to 8.0. They also showed that tomato plants made their best growth with ammonium salts containing no nitrate at pH 8.0 and that ammonium nitrate was most effectively utilized at pH 4.0 to 5.0 Naftel (6) showed that the absorption of ammonium by the cotton plant increased as acidity of the culture medium was reduced; the absorption of nitrates was only slightly affected by the reaction of the medium. He found that the highest absorption of nitrogen occurred at pH 6.0 and was greatest when ammonium and nitrate nitrogens were present. The work reported was presumed to be conducted under sterile conditions. However, the rate of biological nitrification also increases with pH and is most rapid in the pH range near 8.0 (11). The high pH does not necessarily have to result from the use of lime. Recent work (3) has shown that the pH increase due to large concentrations of ammonia also greatly stimulated nitrate production. Therefore, the possibility of some nitrate being produced at the high pH values cannot be ignored. This can be a complicating factor in the interpretation of nitrogen utilization experiments.

Ammonium nitrogen can be used quite effectively by some plants, but the relatively high pH requirement for rapid absorption limits its value for direct metabolism, even on properly limed agricultural soils. The work discussed indicates that both nitrate and ammonium nitrogen are used by many plants. However, it appears that conditions are more favorable in most soils for the utilization of nitrate nitrogen. The fact that nitrate causes more rapid greening of nitro-

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gen-deficient plants than does ammonia is evidence that nitrate is absorbed more readily than ammonia. This has been observed with soils varying from pH 5.0 to 6.5. Visual growth response to anhydrous ammonia in Florida, for example, occurs only after 7 to 10 days, during which time nitrate has been produced.

Nitrification proceeds slowly in many of the sandy soils of Florida. Extreme acidity, light texture, short time of cultivation and low fertility have been shown to be factors (12). Soils in the pH range near 5.0 frequently nitrify poorly (4, 13) and some of the lighter textured soils have not nitrified well even at pH values near 5.5 (2). According to the 10-year summary of soil testing results in Florida by Pritchett (9), about 15 percent of the soils are below pH 5.0 and approximately 50 percent are below 5.5. The addition of lime usually promotes nitrification to a satisfactory rate, and properly limed soils normally are more productive than unlimed, acid soils.

The purpose of this paper is to show the necessity for liming and proper pH control on acid soils when ammoniacal nitrogen, or forms which are converted to ammonia, are used as nitrogen sources.

EXPERIMENTAL METHODS

A nitrogen source experiment was conducted in 1956 on Kanapaha fine sand (pH 5.0) near Gainesville. This soil has relatively poor internal drainage. Anhydrous ammonia, urea and ammonium nitrate were included and were applied at rates of 100 and 200 pounds nitrogen per acre in split application. One-half of each rate was applied in March and one-half in July. Pearlmillet was used as the indicator crop. A randomized block design with three replications was used. Sufficient phosphate and potash were applied in all studies so that they did not limit growth.

Because of the nature of the results obtained in 1956, another field experiment was initiated to include lime in a split-plot design. Two tons of high-calcium lime were used and the soil disked thoroughly. Oats were grown in the fall and winter of 1956-57 and pearlmillet during the summer of 1957. Nitrogen was applied at rates of 50 and 100 pounds per acre to the oats and at rates of 100 and 200 pounds per acre in split application to the pearlmillet.

Forage yields were expressed as oven-dry weights (70 C). The percentage recovery of applied nitrogen was calculated by subtracting the nitrogen recovered in plants produced on untreated soil from that in plants produced on treated areas. Total plant nitrogen was determined by the Kjeldahl procedure. Soil nitrification studies were conducted by a previously described method (3). Soil pH was determined in a 1:2 soil-water suspension with a Leeds-Northrop potentiometer equipped with a thin glass electrode.

RESULTS AND DISCUSSION

Forage yields and the recovery of applied nitrogen for the 1956 experiment on Kanapaha fine sand with pearlmillet are shown in table 1. Forage yield differences approached significance when 100

pounds of nitrogen per acre were used and were significantly different when 200 pounds nitrogen from the different sources were applied. The percentages of applied nitrogen recovered from the nitrogen sources were significantly different. These differences were significant (5 percent level of probability) for the 100-pound rate and highly significant (1 percent level) for the 200-pound rate. Forage yields were lowest from anhydrous ammonia, intermediate from urea and highest from ammonium nitrate. Percentages of plant nitrogen ranked in the same order, but were much more accentuated, so that differences in the applied nitrogen recovered were much larger than were yields. When only 100 pounds of nitrogen were applied, less than half as much nitrogen was recovered from anhydrous ammonia as from ammonium nitrate. Urea was intermediate. The relatively poor response from anhydrous ammonia compared to that of urea could have resulted from the initial application losses of anhydrous ammonia previously reported (1). Inhibition of nitrification previously shown for very high concentrations of ammonia (3) probably was not a factor, since the percentage recovery of nitrogen from anhydrous ammonia applied at 200 pounds nitrogen per acre was considerably improved. The improvement at the higher rate may have been due to a stimulation of nitrification resulting from the increased pH in the retention zone (1, 3). The broadcast application of urea did not increase the pH to the same extent as the band application of anhydrous ammonia and, therefore, did not cause a stimulation of nitrification. The percentage recovery of applied nitrogen was not appreciably changed with rate of nitrogen application for urea and ammonium nitrate.

Previous studies with similar soils which had relatively high acidity frequently have shown extremely poor nitrification. It has been shown also that ammonium is absorbed poorly by plants growing in media as acid as this soil. For these reasons and the relatively poor results obtained in 1956 with anhydrous ammonia and urea, another experiment was initiated that winter to determine whether these reduced forms of nitrogen could be used effectively when the soil pH was increased to a more desirable range.

TABLE 1.—Forage Yields and Percentage Recovery of Applied Nitrogen from Pearl Millet Grown on Kanapaha Fine Sand at pH 5.0.

Nitrogen Applied lbs./A	Nitrogen Source	Yield lbs./A	Applied Nitrogen Recovered %
Check		3790	----
100	Anhydrous ammonia	5090	32.0
100	Urea	5950	49.2
100	Ammonium nitrate	6200	74.0
L.S.D. .05		N.S.	24.4
200	Anhydrous ammonia	7070	45.5
200	Urea	7200	53.8
200	Ammonium nitrate	8200	73.2
L.S.D. .05		927	15.7
L.S.D. .01		N.S.	26.2

After applying the lime and allowing several weeks for its reaction with the soil, a laboratory nitrification study was made; the data are tabulated in table 2. Ammonium sulfate was used as the source of nitrogen. Unlimed and field limed soils were used, with an additional laboratory lime treatment. Where no nitrogen was applied neither lime treatment had any effect on nitrification of soil nitrogen. Considerable nitrate was produced in field and laboratory limed soils to which ammoniacal nitrogen had been added. The unlimed soil nitrified to only a very limited extent even with ammonium sulfate.

TABLE 2.—The Effect of Lime on Nitrification in Kanapaha Fine Sand.

No Nitrogen Added				Nitrogen Added 200 ppm N as $(NH_4)_2 SO_4$			
Unlimed		Limed*		Unlimed		Limed*	
NO_3—N ppm	pH	NO_3—N ppm	pH	NO_3—N ppm	pH	NO_3—N ppm	pH
No Lime Applied in Field							
14	4.4	13	6.0	4	4.5	51	5.2
2 Tons Lime Field Applied							
10	5.8	14	6.6	25	5.6	68	6.0

*$CaCO_3$ equivalent to 2 tons per acre applied in laboratory.

Oats were grown on this experimental area during the winter and spring of 1956-57. Fifty and 100 pounds of nitrogen per acre were applied in October. Forage yields and plant recovery of applied nitrogen are shown in table 3. In the statistical treatment of these data, forage yields from nitrogen sources were significantly different. The differences were significant for the 50-pound rate and highly significant for the 100-pound rate. The nitrogen source x lime interaction was also significant when 100 pounds of nitrogen were applied. Differences in yields and nitrogen recovery resulting from the lime treatments were not significant because of the differential effect of lime on the nitrogen sources. Nitrogen recovery differences from nitrogen sources were significantly different only when 100 pounds of nitrogen were applied, but approached significance at the lower rate. This also was apparently due to the differential effect of lime on the nitrogen sources. The nitrogen sources x lime interaction was significant at the 50-pound rate and highly significant at the 100-pound rate of application. The data in table 3 and table 4 are arranged so that the nitrogen source x lime interaction can be observed. Ammonium nitrate produced about 50 percent more forage than did anhydrous ammonia or urea in the unlimed soil. Compared to ammonium nitrate, where 50 pounds of nitrogen were used, anhydrous ammonia was about one-fourth as

high and urea about one-third as high in recovery of applied nitrogen. Results were similar where 100 pounds nitrogen per acre were used, but there was some improvement for anhydrous ammonia. Again the relatively better response at the higher rate may have been due to the higher initial pH in the retention zone. The addition of lime caused a marked increase in yield and nitrogen recovery for anhydrous ammonia and urea. Response to anhydrous ammonia on the limed soil was equivalent to that from ammonium nitrate on the unlimed soil and was superior to ammonium nitrate on the limed soil. Response to urea was improved considerably but not to the same extent as was anhydrous ammonia, particularly in plant nitrogen recovery. Ammonium nitrate was not as efficient in the limed soil as in the unlimed soil with respect to recovery of applied nitrogen. Forage yields from ammonium nitrate were not appreciably altered. The most apparent reason for this is that excessive leaching of nitrate nitrogen from the limed soil occurred in the late spring.

TABLE 3.—Forage Yields and Percentage Recovery of Applied Nitrogen from Oats Grown on Unlimed and Limed Kanapaha Fine Sand

Nitrogen Applied lbs./A	Nitrogen Source	Yield lbs./A	Applied Nitrogen Recovered %	Yield lbs./A	Applied Nitrogen Recovered %
		pH 5.0		pH 6.0*	
Check		1840	0	1880	0
50	Anhydrous ammonia	2340	13.8	3400	51.2
50	Urea	2260	18.2	2570	37.0
50	Ammonium nitrate	3430	53.6	3130	35.6
100	Anhydrous ammonia	2510	23.1	2940	44.2
100	Urea	2020	17.2	2850	28.1
100	Ammonium nitrate	3320	45.4	3160	33.5

*Two tons high-calcium lime per acre applied.

TABLE 4.—Forage Yields and Percentage Recovery of Applied Nitrogen from Pearl Millet Grown on Unlimed and Limed Kanapaha Fine Sand.

Nitrogen Applied lbs./A	Nitrogen Source	Yield lbs./A	Applied Nitrogen Recovered %	Yield lbs./A	Applied Nitrogen Recovered
		pH 5.0		pH 6.0*	
Check		2630	-----	2590	
100	Anhydrous ammonia	4640	26.0	5860	45.2
100	Urea	4560	34.7	7190	75.6
100	Ammonium nitrate	5590	45.2	5550	45.5
200	Anhydrous ammonia	8140	46.6	9890	66.7
200	Urea	7600	50.5	7960	55.9
200	Ammonium nitrate	8050	56.3	7190	43.9

*Two tons high-calcium lime per acre applied.

Pearlmillet was grown on the Kanapaha experimental area during the summer of 1957 with similar though somewhat less marked results. One hundred and 200 pounds of nitrogen per acre were applied in split application. Yield differences due to the nitrogen source x lime interaction were significant. Differences at the 100-pound nitrogen application were highly significant and at the 200-pound rate were just below the 5 percent level of significance. Yield differences due to lime and nitrogen sources were not significant. Differences in plant recovery of nitrogen from the different sources also were significant only for the nitrogen source x lime interaction. These differences were significant when 100 pounds of nitrogen were applied and highly significant when 200 pounds were applied. Percentage recovery of applied nitrogen for all nitrogen sources was somewhat higher at the 200-pound rate than at the 100-pound rate. Liming the soil resulted in increased recovery of nitrogen from anhydrous ammonia and urea, but the recovery was less from ammonium nitrate. Liming increased the plant calcium content by 20 to 30 percent. Potassium, phosphorus and magnesium were not appreciably altered.

SUMMARY AND CONCLUSIONS

Anhydrous ammonia and urea produced relatively low yields of pearlmillet and oat forage, and low plant recovery of the applied nitrogen compared to ammonium nitrate on the acid, Kanapaha fine sand (pH 5.0). Liming the soil resulted in marked improvement in yields of oat and pearlmillet forage and in plant recovery of nitrogen applied as anhydrous ammonia and urea. Recovery of nitrogen from ammonium nitrate was somewhat less from the limed area. Nitrification in the unlimed soil was very poor. Two tons of lime per acre in the field increased the pH to 6.0 and resulted in a marked increase in the rate of nitrification.

Efficient utilization of reduced nitrogen sources, such as anhydrous ammonia and urea, in Floridas acid, sandy soils will necessitate better soil management. Primary attention should be directed towards maintaining the soil reaction between pH 5.5 and 6.5 by the judicious use of lime.

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Effects of Nitrogen Source, Subsoil pH and Substrate Amendments on the Growth of Orange Seedlings

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INTRODUCTION

Much interest in nitrogen sources and soil pH has been aroused in Florida in recent years primarily as a result of the recognition of copper-toxicity damage to citrus on excessively acid soils (9). The main factor contributing to development of soil acidity is the sulfofication of the large amount of sulfur applied in the pest-control program. Certain nitrogen sources are contributory factors in soil-acidity development primarily as a consequence of nitrification processes.

It is now fairly well established that citrus production is essentially equal when trees are grown with equivalent levels of nitrogen supplied by any one of a wide range of nitrogen materials, provided proper attention is given to pH control (10, 12, 15). Acidity from sulfofication has the possibility of being eliminated as a cultural factor through the development of a substitute material for sulfur. Nitrification, however, appears to be an inevitable factor since nitrogen must be used, and the baseless carriers of nitrogen have an economic advantage over the base-carrier forms. Consequently, it seems advantageous to learn as much as possible about the factors involved in nitrogen fertilization.

While the ill effects that sometimes result from the use of an ammoniacal source of nitrogen on citrus is always associated with substrate acidification (2, 4, 5, 10, 11, 12, 16), the exact cause of poor growth is not always clear. Some authors, for instance, have attributed the poor growth to lack of nitrification and ammonia toxicity assuming that citrus cannot directly utilize ammoniacal nitrogen (4, 10). However, recent studies have shown that it is possible to sustain normal growth entirely on ammoniacal nitrogen and that poor growth results from excessive acidity regardless of nitrogen source (11).

The results herewith presented are a part of a series of experiments on the nitrogen nutrition of citrus. The principal objectives were to extend previous observations and results on the relation of pH to growth and to explore the site of acidity development from ammoniacal nitrogen applications.

MATERIALS AND METHODS

One hundred 8-inch, glazed, clay tiles 3 ft. in length were sunk in the ground as outdoor-culture vessels. The bottom ends were open to the sandy subsoil to permit ready drainage. Each tile held about 100 lbs. of sand or soil. Three parent materials were used as substrates, and these were given certain amendments as described below and in table 2.

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TABLE 1.—Mean pH Values of Soil Samples by Arithmetic Computation from Individual Samples and by pH Determination on a Composite Sample

Example	pH values of soil samples	Arithmetic mean	pH of composite
1	6.25, 6.35, 6.40, 6.60, 6.65, 6.76, 7.00	6.57	6.60
2	4.85, 5.00, 5.05, 5.07, 5.10, 5.15, 5.35	5.08	5.05
3	4.60, 4.65, 4.80, 4.80, 4.95, 5.15	4.80	4.80
4	4.70, 4.80, 5.45	4.97	4.98
5	6.35, 6.76, 7.00	6.70	6.70
6	5.05, 5.20, 5.65	5.30	5.30
7	4.65, 4.75, 5.05	4.82	4.85
8	4.05, 5.05, 6.25	5.12	5.08

TABLE 2.—Mean Dry Weights (gm) of Orange Seedlings Minus Leaves Grown Outdoors in 8-inch Glazed Tile Extending 36 Inches in the Ground Using the Indicated Substrates and Solutions

Substrate and amendment	Nitrogen source[1] $(NH_4)_2SO_4$	NH_4NO_3	75% NO_3
Orlando f.s. subsoil	51.2	50.4	54.5
Orlando f.s. subsoil + dolomite[2]	57.2	52.0	57.4
Lakeland f.s. subsoil + sulfur[3]	14.5*	33.5*	48.0
Lakeland f.s. subsoil + dolomite[2]	58.0	52.0	55.0
Sand	19.5*	24.5*	38.0*
Sand + dolomite[2]	35.0*	40.0*	34.0*
Sand + dolomite (top 4")[4]	51.5	----	--
Sand + colloidal PO_4 (top 4")[5]	51.4	-----	-----
Sand + vermiculite[6]	46.0*	--	-----
Sand + $CaSO_4$ (top 4")[7]	45.5*	.	.
Sand + dolomite gravel[8]	38.5*	.	.
Sand + colloidal PO_4 (bottom ½)[9]	37.5*	-----	-----
Sand + dolomite (bottom ½)[10]	30.5*	-----	-----
Sand + $CaSO_4$ (bottom ½)[11]	23.5*	-----	-----

L.S.D. at odds of 19:1 between any two means is 7.7; * indicates significant depression of growth.

[1]Solutions for Orlando soil contained N source and B only. All other cultures received complete nutrient solutions (11).

[2]0.2 lb. dolomite in 100 lb. soil or sand mixed throughout column.

[3]0.2 lb. powdered sulfur in 100 lb. soil mixed throughout column.

[4]1.5 lb. dolomite mixed with 13.5 lb. sand in top 4 inches.

[5]5 lb. colloidal PO_4 mixed with 10 lb. sand in top 4 inches.

[6]2.75 lb. Ca-vermiculite in four 1½-inch columns through sand.

[7]3 lb. $CaSO_4$ mixed with 12 lb. sand in top 4 inches.

[8]5 lb. dolomite gravel in 95 lb. sand mixed throughout column.

[9]21 lb. colloidal PO_4 mixed with 25 lb. sand in bottom half.

[10]7.5 lb. dolomite mixed with 42.5 lb. sand in bottom half.

[11]20 lb. $CaSO_4$ mixed with 25 lb. sand in bottom half.

A. *Orlando fine sand subsoil.*—A bulk quantity of this soil (6-20" depth) was taken from the site of a former orange grove used for a city subdivision about 1940. This was a dark sand with about 0.5 percent humus and contained considerable phosphorus (800 ppm total P) as a result of many years of fertilization. Neutral ammonium acetate exchange capacity determination showed 0.8 m.e. per 100 g of soil. The soil was mixed to homogenize it, and screened dolomitic lime (20-mesh and finer) was mixed with half of the soil at the rate of 0.2 lb. per 100 lb. of soil. This approximates a lime rate of 2 tons per acre 6" of soil. Twenty-four tiles were filled with the limed soil and an equal number with untreated soil in September 1954. In April 1955, after repeated leachings with rainwater, the pH readings were 5.65 for the untreated soil and 7.40 for the limed. Thirty-six of the tiles were planted in mid-April in a 3 x 3 x 2 factorial experiment with duplicate cultures. $(NH_4)_2SO_4$, NH_4NO_3, and a 50:50 mixture of NH_4NO_3 and $Ca(NO_3)_2$ which gave all NH_4, 50% NO_3, and 75% NO_3, respectively, were applied as single solutions at an annual rate of 250 lb. N per acre. Besides the nitrogen sources the solutions contained only a trace of boron. Three methods of timing were compared by making weekly, monthly, and quarterly applications of the constant yearly supply of N. The 2-level factor was the presence and the absence of dolomitic lime.

The 12 unplanted tiles were used in a supplementary test in which monthly applications of each N source, in duplicate, were given to untreated and dolomited soil. The cultures were kept barren throughout the test period.

B. *Lakeland fine sand subsoil and quartz sand.*—A similar procedure was followed with this soil, taken between the rows of a 12-year-old orange grove, except for mixing sulfur in half the soil In this case 9 tiles contained sulfur and 9 dolomite. This soil at the rate of 100 g per 100 lb. soil rather than leaving it untreated. showed an exchange capacity of 0.3 m.e. per 100 g. In April, after 6 months of standing and repeated leachings, these showed pH readings of 4.4 and 7.4, respectively. These 18 tiles were used in conjunction with 18 other tiles filled with fine, white, quartz sand, half of which contained 0.2 percent dolomite (pH 7.4) in a 3 x 3 x 2 factorial experiment with triplicate cultures. In this case the above 3 N sources were compared on 2 substrates (soil and sand) at 2 lime levels (dolomite and sulfur or untreated sand). The N sources were used in complete culture solutions similar to those previously described (11), and these were applied monthly at a rate which equaled the 250 lb. N per acre per year used in A.

C. *Modified sand.*—Eight miscellaneous treatments, in duplicate, were included for the purpose of supplying calcium in various ways. These consisted of mixtures of white sand with dolomite, colloidal phosphate, gypsum, or calcium-saturated vermiculite in the various ways indicated in table 2. These 16 cultures received the complete culture solution containing all $(NH_4)_2SO_4$ as a N source once a month.

All cultural vessels were set up in September 1954 and treated exactly the same way for the next 27 months except for differential solutions and the absence of plants in 12 tiles as indicated under A. The pre-planting period, from September to April, was to allow time for lime and sulfur reactions and the leaching out of salts. In mid-April 2 plants from a uniform supply of 6-month-old Pineapple orange seedlings were used to plant each of 88 tiles. Every Monday each tile received 500 ml of water or solution, depending on its schedule, and every Thursday 1 liter of rainwater. Solution treatments were started on April 29, 1955 and continued until October 30, 1956.

After 18 months the solutions were stopped, and water in excessive but equal amounts was applied frequently over a 3-month period, after which extensive depth sampling was done in the soil columns to determine the pH and extractable-Ca status. The pH determinations were made on air-dried soil with a glass electrode meter with a 1:1 water suspension. Ca was extracted with excess 0.1 N HCl and assayed on the flame photometer. After this the tiles were removed from the ground and the substrates washed out so that the entire root systems could be obtained. The plants were dried and weighed without the leaves, since partial defoliation was caused by a frost a few days before harvest.

In addition to the results of these tests some data on pH from field plots are discussed briefly since it has a bearing on the method of handling pH data.

RESULTS AND DISCUSSION

Soil pH.—The literature is replete with misinformation on soil pH. Many papers and even textbooks treat soil pH as though they were dealing with simple H-ion concentration. Thus, data are frequently converter to logarithmic figures using the formula $pH = \frac{1}{\text{Log H}}$ and the resulting values are used in figuring mean pH values. This may give a highly erroneous impression for, as shown by Bradfield (3), Peech (6) and others, soil pH is often most nearly reflected by the formula $pH = pK + \log \frac{\text{Sum of exchangeable bases,}}{\text{Exchangeable H}}$ in which the dissociation constant pK is equal to that pH value resulting when the exchange capacity is half saturated with acid. Peech (6) found pH 5.5 to be the half-saturation point of both surface and subsoils in Florida. Examination of the mathematical nature of the log of a fraction shows that the log value is very small when the ratio is near 1 and, of course, vanishes at 1. This means that the log factor can be neglected in working with pH values near 5.5 and that the pH values can be used arithmetically. In practice pH values from about 4.5 to 6.5 can be treated in this way with sufficient precision for most purposes. Of course, the pH values of soils with different exchange capacities cannot be averaged together. Table 1 illustrates the validity of treating pH data arithmetically when working with samples of fairly similar soil. The individual pH values shown are from field fertilizer plots distributed over about 10 acres of grove. These ex-

amples are drawn from 3 separate experiments representing both Lakeland and Eustis soil types. Each line in the table represents plot replicates of either top or subsoil in a given test grove. The composite pH was determined by mixing equal volumes of soil from each sample and then determining the pH of the mixture. Because of the good agreement found, the pH data presented in this paper were treated arithmetically and only replicate means are presented.

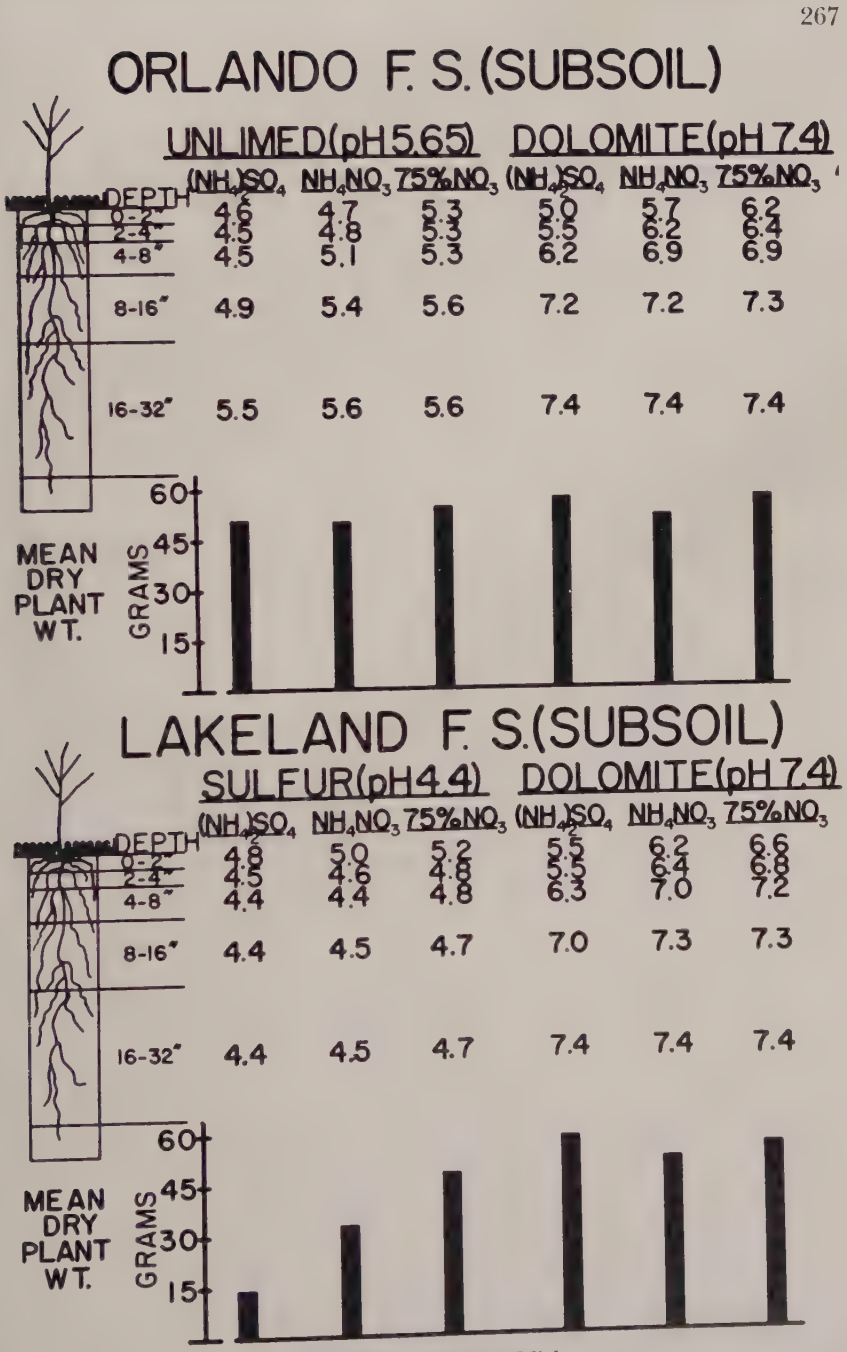
Studies by Volk and Bell (14) showed that in limed soils there was often an erratic association between pH and apparent percent base saturation. They attributed this largely to the presence of unreacted lime particles which tended to dissolve in the extractant solution, thereby giving unduly high base content. Their lime studies, however, and all lime tables show a proportionate relation between pH change and the amount of lime in the range from pH 4 to about 7, which again attests the practicability of treating pH data arithmetically without conversion to logarithmic values.

Growth of orange seedlings.—The mean dry weights per seedling minus leaves in all treatments are summarized in table 2, and certain treatments are depicted graphically in figure 1. On Orlando subsoil neither the nitrogen source nor the presence of dolomite materially affected growth. The 3 methods of timing the applications of N likewise had no effect on growth, and therefore no data are presented.

There were some striking differences in growth of seedlings in the Lakeland subsoil associated with nitrogen source and pH (table 2 and figure 1). When dolomite was added good growth occurred regardless of nitrogen source, but in the sulfur-acidulated soil growth ranged from very poor to nearly normal as the proportion of nitrate nitrogen increased. This same trend was evident in the white-sand cultures, but even the best growth was inferior to that in the two subsoils. This is attributed to a lower moisture-retaining capacity of the sand since these plants sometimes wilted slightly. This is substantiated, too, by the fact that mixing fairly large amounts of colloidal materials in the top 4 inches of sand gave increased growth. Dolomite and colloidal phosphate both gave very good growth when used in this way.

Two other sand modifications gave some improvement in growth when compared with sand or sand with 0.2 percent dolomite, but growth was still substandard when compared with that from the best treatments. These modifications were $CaSO_4$ in the top 4 inches and Ca-vermiculite in vertical columns. $CaSO_4$ appeared to increase the moisture-holding capacity of the sand without raising the pH as much as dolomite or colloidal phosphate did. The final pH was 4.5 in the zone containing $CaSO_4$; 8.3 in the high dolomite zone; and 5.6 in the top 4 inches containing colloidal phosphate. There was prolific root growth in the small vermiculite columns, but very weak growth in the surrounding sand.

One of the best root systems developed in the sand columns with coarse dolomitic gravel; however, like the plants in the 0.2 percent dolomite they appeared to suffer somewhat from lack of continuous moisture and were substandard in size. When colloidal materials were put only in the bottom half of the sand column, growth was



LEGEND TO FIGURE 1.

Figure 1.—Final pH values for various depths in columns of Orlando f.s. and Lakeland f.s. subsoils showing the change from the original pH by 18 months of application of N from the source indicated at the rate of 250 lb. N per acre and the resulting growth of Pineapple orange seedlings expressed as mean dry weight per plant (minus leaves).

very poor for many months, but the trees over the colloidal phosphate made considerable growth in the latter stages of the experiment. At harvest time very poor root development had occurred in the sand of the top half of the column, but rather extensive root proliferation had taken place in the colloidal phosphate mixture in the bottom. $CaSO_4$ or dolomite in the bottom of the column did not materially improve growth.

In general these growth responses agree with those obtained in other studies on nitrogen source and pH (1, 2, 4, 5, 10, 11, 12). The adverse effects of ammonia fertilization are associated with excess acidity and may be offset by liming materials. The lack of control of nitrification in solid substrates does not permit a precise conclusion as to cause and effect. However, one of the possible explanations, in harmony with solution culture evidence, is that excessive acidity development from ammoniacal N is directly detrimental to growth (11), and the slow-down or failure of nitrification under acid conditions is only coincidental.

Acidity development.—Extensive pH measurements were made on the columns of soil at the end of the test period. In the cultures with good growth most of the soil column had a pH of 4.6 or above, thus agreeing with the results reported in a companion paper (8). Except for the data from the sulfur-treated Lakeland subsoil, all showed an acidity gradient from the top downward. This is particularly evident in the dolomited columns (fig. 1 and tables 3, 4 and 5). The trends were similar in the absence of plants (table 3), thus indicating that absorptive processes of roots played a minor part in acidity development. In fact, in unlimed soil the trend was for plant feeding to reduce acidity development. Thus, it is evident that acidity changes were related to nitrification and all 3 sources of N were acidifying to varying degrees. The digestion of lime in the upper depths first indicates that, even with the low exchange capacities of these subsoils NH_4 was screened out and nitrified there. This is in harmony

TABLE 3.—Mean Effect of Monthly Applications of Nitrogen from 3 Sources at the Rate of 250 Lb. N Per Acre Per Year on the Final pH of Untreated and Dolomited Orlando f.s. Subsoil with and without Orange Seedlings

Lime treatment	Depth (inches)	$(NH_4)_2SO_4$		NH_4NO_3		75% NO_3	
		Planted	Barren	Planted	Barren	Planted	Barren
None (Orig. pH 5.65)	0-2	4.6	4.5	4.7	4.6	5.3	5.0
	2-4	4.5	4.4	4.8	4.6	5.3	4.8
	4-8	4.5	4.4	5.1	4.6	5.3	4.9
	8-16	4.9	4.7	5.4	5.0	5.6	5.3
	16-32	5.5	5.0	5.6	5.5	5.6	5.6
0.2% Dolomite (Orig. pH 7.4)	0-2	5.0	5.0	5.7	5.7	6.2	6.1
	2-4	5.5	5.5	6.2	6.1	6.4	6.4
	4-8	6.2	6.2	6.9	6.8	6.9	6.8
	8-16	7.2	7.2	7.2	7.3	7.3	7.3
	16-32	7.4	7.4	7.4	7.4	7.4	7.4

with field studies in which no movement of NH_4 to the subsoil was detected following a fairly high rate of fertilization of grapefruit on Lakeland fine sand with $(NH_4)_2SO_4$ (12). These results indicate that subsoil acidity is primarily a result of the downward movement of acid (H-ions) and not the downward movement of potentially acidifying materials which later generate acidity. Topsoil neutralization of excess acidity by liming is therefore a practical procedure, and no doubt this largely accounts for the failure of demonstrating any preferential source of N by citrus in experiments using lime for pH control (4, 10, 12, 14).

The pH values found in the sulfur-treated Lakeland subsoil probably are a result of some acid displacement by base cations in the culture solutions (table 6), thus accounting for the higher pH values

TABLE 4.—Mean Effect of an Annual Rate of 250 Lb. N Per Acre from 3 N Sources Applied at Different Time Intervals on the Final pH at Various Depths in Soil Columns Supporting Orange Seedlings

Substrate	Depth (inches)	Timing of N application		
		Weekly	Monthly	Quarterly
Orlando f.s. series (original pH 5.65)	0-2	4.73	4.93	5.02
	2-4	4.78	4.88	4.78
	4-8	4.93	5.12	4.90
	8-16	5.17	5.45	5.23
	16-32	5.40	5.83	5.56
Orlando f.s. plus dolomite series (original pH 7.4)	0-2	5.45	5.65	5.77
	2-4	5.95	6.17	5.97
	4-8	6.65	6.96	6.45
	8-16	7.18	7.26	7.40
	16-32	7.42	7.40	7.40

TABLE 5.—Relative Acidifying Effect of NH_4NO_3 and $(NH_4)_2SO_4$ in at Which a Given pH Was Found After 18 Monthly Unplanted Orlando Subsoil Columns as Measured by the Depth Applications of 21 Lb. N Per Acre

pH	Depth in inches		Depth ratio
	NH_4NO_3	$(NH_4)_2SO_4$	
6.6	2.5	6.8	2.72
6.7	3.0	7.2	2.40
6.8	3.5	7.5	2.14
6.9	3.8	8.0	2.10
7.0	4.2	8.5	2.02
7.1	4.5	8.8	1.95
7.2	5.0	9.2	1.83
7.3	5.5	9.5	1.72
7.4	6.2	10.5	1.69
Mean	---	---	2.06

TABLE 6.—ppm Ca Extracted With 0.1 HCl from Orlando and Lakeland Fine Sand Subsoils at the Start and at Various Depths at the End of the Test Period

Sample depth	Unlimed Orlando (46 ppm Ca)			Dolomited Orlando (300 ppm Ca)		
	$(NH_4)_2SO_4$	NH_4NO_3	75% NO_3	$(NH_4)_2SO_4$	NH_4NO_3	75% NO_3
			PLANTED			
0-8″	—	—	—	58	151	154
0.16″	6	16	18	—	—	—
			BARREN			
0-8″	—	—	—	45	130	155
0-16″	3	3	7	—	—	—
	Sulfured Lakeland (1 ppm Ca)			Dolomited Lakeland (294 ppm Ca)		
			PLANTED			
0-2″	5	7	19	16	47	61
2-4″	2	2	6	31	56	59
4-8″	1	1	5	17	66	69
8-16″	1	1	4	103	193	135
16-32″	1	2	3	190	255	234

in the upper depths. Nitrification apparently played some part here in supressing the pH, since the supplies of K, Ca, and Mg were constant in all 3 N-source solutions, and yet the greatest rise of pH was in the culture receiving the least NH_4 (fig. 1).

Relation of N timing to pH change.—Dividing the year's supply of N into 52, 12, or 4 portions was mostly without effect on the resulting pH at different depths. Since all 3 N sources showed similar behavior in this respect, the data were combined in table 4 to show the relation of timing of application to pH. The only suggestion of a trend is for a slightly greater movement of acidity into the lower depths as a result of the most frequent applications on the untreated Orlando subsoil. While this is of doubtful significance, it is contrary to expectancy if one assumes that there would be greater downward movement of NH_4 with the relatively larger, infrequent applications where subsequent nitrification would give lower pH values at lower depths. Thus, these data attest to the generation of acidity in the upper depths regardless of frequency of application.

Relative acidity development from NH_4NO_3 and $(NH_4)_2SO_4$.—Chemical calculations show that for a given quantity of N, $(NH_4)_2SO_4$ is twice as acidifying as NH_4NO_3 when both are completely nitrified (7). An attempt was made to measure this effect in the soil by lime loss in the soil columns at different depths. The results were very erratic because of the difficulties involved in assaying, such as the slowness of reaching equilibrums in extractions or titrations. It was decided to approach the problem through pH readings at different depths. The unplanted, dolomited Orlando subsoil columns were used for the study. The soil was removed in 1-inch layers, and dried at

air temperature, and pH values were obtained for each layer. The pH was thus used as an indication of relative acidity development by plotting pH against depth. Fractions of inches were read by extrapolation to a given pH to the point where the pH was unchanged from the original pH (7.4). The depths of acid penetration from the two sources could then be expressed as a ratio (table 5). The overall average (2.06) showed very good agreement with expectancy (2.00), indicating that the generated acidity from $(NH_4)_2SO_4$ was twice as great as from NH_4NO_3. It can be seen, however, that the movement ratio is not constant for all pH levels. The implications of this are not entirely clear, but it would appear that, since Ca movement is involved, the anion carrier might affect the rate of movement. In one case Ca $(NO_3)_2$ alone would result from nitrification and in the other case half of the Ca would move as $CaSO_4$.

Change in soil Ca status.—Tables 3 and 4 and figure 1 show that all the N sources used were acidifying. The loss of Ca shows a parallel relation to the increase in acidity. Data presented in table 6 show a Ca loss at all depths sampled. As with pH, there is a striking similarity between the Ca contents of the planted and unplanted Orlando subsoil. This indicates that nitrification processes are associated with Ca movement and the presence of a root system has little effect other than a tendency to reduce Ca movement.

The sulfur-treated Lakeland subsoil increased slightly in Ca content as a result of some exchange with the Ca in the culture solution. These changes were largely in the upper depths and parallel the increased pH values found to occur during the experimental period (fig. 1) This soil was practically devoid of extractable Ca when the orange seedlings were planted, showing less than 1 ppm Ca.

The dolomited Lakeland subsoil showed a loss in Ca at all depths, but the biggest changes occurred in the upper depths. The loss of Ca from the lower depths probably is the result of the solubilizing effect of the residual nutrient salts on the lime, which could remove Ca without involving H or changing the pH.

Effect of N source and dolomite on leaf Mg.—Ammonium absorption has been shown to reduce base mineral absorption by citrus (4, 11). One solution culture study (11) showed that leaf calcium in particular was lowered by NH_4; leaf K was slightly lowered but Mg was not affected. In other solution culture studies (4) leaf Mg was found to be strongly depressed, leaf K slightly depressed, and leaf Ca virtually unaffected by NH_4. In the present study also Mg was the most affected base cation. Table 7 shows the mean values for leaf Mg at the end of the experiment. In the absence of dolomite, the Orlando subsoil cultures showed little evidence of a trend, but the Mg supply was only the small amount carried by the soil itself and all plants showed mild leaf symptoms of Mg deficiency. In the Orlando cultures containing dolomite and in all the Lakeland subsoil and white-sand cultures, which received complete nutrient solutions, there was a definite trend toward reduced leaf Mg as the supply of NH_4 increased.

Little evidence exists as to whether the Mg in dolomite ever becomes available to the citrus tree in appreciable amounts. Mg de-

TABLE 7.—Effects of Nitrogen Source and Dolomite on the Percentage of Magnesium in the Leaf Dry Matter

Substrate	$(NH_4)_2SO_4$	NH_4NO_3	75% NO_3
	Without dolomite		
Orlando f.s.	0.12	0.13	0.13
Lakeland f.s.	0.13	0.18	0.31
White sand	0.17	0.26	0.30
	With 0.2% dolomite		
Orlando f.s.	0.28	0.30	0.31
Lakeland f.s.	0.25	0.28	0.28
White sand	0.24	0.31	0.36

ficiency in Florida citrus was first alleviated by dolomite, but the response was relatively slow (13). The general assumption has been that while some nutritional benefit results from applications of dolomite, the supply of Mg from this source is inadequate for citrus. The data in table 7 show that an adequate level of leaf Mg for orange seedlings can be obtained with dolomite as the sole source of Mg. In fact, leaf Mg was as high in the Orlando subsoil cultures with dolomite alone as it was in the Lakeland subsoil and white sand cultures which had both dolomite and water-soluble Mg.

SUMMARY

Growth of Pineapple orange seedlings in columns of subsoil and sand was reduced by acid-forming sources of nitrogen unless the acidity was counteracted by additive substances or by the soil itself. Marked growth reduction occurred in Lakeland fine sand subsoil when the pH was about 4.5 or less and in unbuffered sand.

pH changes in the columns, with and without plants, showed that acidity development was attributable primarily to nitrification since they were proportionate to the acidulating capacity of the nitrogen source.

pH changes also indicated that acidity development occurs mostly in the upper soil depths and progresses downward only after the exhaustion of the neutralizing capacity in the upper depths.

Nitrogen timing, in which frequent applications of small amounts of N were compared with less frequent but larger amounts of N, showed that the acidity development pattern was essentially the same. Thus, even with very low exchange capacity, NH_4 appeared to be screened out and nitrified in the upper few inches regardless of the method of distributing a given rate of N.

pH determinations by depths showed that, on the average, acidity from ammonium sulfate nitrification moved twice as far into a limed soil column as did that from ammonium nitrate. This confirms theoretical considerations which show that nitrification of $(NH_4)_2SO_4$ generates twice as much acidity as does nitrification of NH_4NO_3.

Loss of Ca in the subsoils tended to parallel the development of acidity in that the greatest loss was from the upper depths.

Leaf analysis showed that orange seedlings can obtain adequate Mg from dolomite for normal growth irrespective of N source, but NH_4 tended to depress Mg absorption in these tests.

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Liming Experiments and Observations with White Dutch Clover on Immokalee Fine Sand[1]

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INTRODUCTION AND REVIEW OF LITERATURE

The effects of liming and soil acidity on nodulation and legume vigor have been a subject of discussion for many years. PH, soil calcium levels, and more recently molybdenum have been found to play important roles (1, 3, 5, 6, 7, 8, 13, 20). Albrecht (2), in 1941, suggested that small quantities of limestone, when drilled with the seed, were of equal benefit to larger broadcast applications. Australians have made commercial use of this in recent years (4, 5) by drilling lime at 200 pounds per acre with sub clover seed. Loneragan and coworkers (18) found that pelleting 10 pounds of sub clover seed with 5 pounds of finely ground calcium carbonate was as effective as drilling 200 pounds with the seed. Ammoniated superphosphate drilled with the seed also was effective (19). Increased applications of inoculant and high soil moisture were found by Spencer to increase nodulation (23).

In Florida, studies on the movement of lime have been made by Volk and Bell (24), Harris (15), and Volk (25). Little downward movement of lime occurred, particularly in acid soils. Many workers have indicated that between 1 and 2 tons of lime are needed on flatwoods soils for maximum legume growth (9, 11, 14, 16). In 1957, recommendations (22) included a statement that a soil pH of from 6.0 to 7.0 is needed for maximum clover production, and 1,800 pounds per acre of available calcium is needed on sandy soils. Furthermore, 2 to 3 tons of lime per acre should be applied initially on most new land, with 1 ton additional every 3 years.

The effects of lime and phosphate sources were studied by Blaser, Volk, and Smith in 1941 (10). No white clover yield differences were found as a result of the following treatments in addition to 100 pounds of potash per acre: hi-calcic lime-2,000, superphosphate-600, dolomite-1,000; hi-calcic lime-2,000, superphosphate-300; rock phosphate-3,000, hi-calcic lime-500; rock phosphate-3,000, hi-calcic lime-500, superphosphate-200; rock phosphate-3,000, hi-calcic lime-2,000; colloidal phosphate-3,000, hi-calcic lime-500; and hi-calcic-2,000, basic slag-750 pounds per acre.

Little is known of the relationship between soil calcium or magnesium content and white clover growth and few, if any, reports are available on the lime requirements of clover-grass growth following

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vegetables. In this paper are presented results of field and greenhouse liming experiments obtained from forage growing on sandy soils in Southern Florida.[3]

MATERIALS AND METHODS

Soil samples were analyzed according to routine Everglades Experiment Station methods (12). Field samples were obtained from a composite of borings to a depth of six inches, while greenhouse samples were obtained from a homogenous mixture of the soil from each pot. Cations were extracted with 0.5 *N* acetic acid and estimated on the Beckman DU flame photometer. Phosphorus was extracted with distilled water, and pH was determined with a glass electrode using equal volumes of soil and water.

All plots were harvested with a sickle bar mower and data are reported on the basis of material dried at 70 to 75° C. in a forced-draft oven. Nitric-perchloric acid digestion was used for mineral analyses of clover and chemical techniques were similar to those reported elsewhere (17), except for calcium. Sufficient phosphoric acid to supply 5 mg. of phosphorus per 100 ml. of solution was added to both the calcium standards and the unknown solutions, to equalize the irregular depressing effect of normal variations in plant phosphorus on the calcium readings.

The statistical procedures described by Paterson were used (21).

Hi-calcium limestone had the following minimum guaranteed analysis: $CaCO_3$—87%, passing 60-mesh sieve—50%, passing 20-mesh sieve—80%, moisture (not more than)—10%. Tennessee ground open hearth basic slag was used. Chemical and physical analyses of the basic slag, hydrated lime, gypsum, and dolomite used are reported in another paper (17). In this work gypsum will be considered as a soil amendment.

EXPERIMENTAL PROCEDURES AND RESULTS

1. Lime Experiment on Virgin Soil—The experiment was begun in August 1952 on Immokalee fine sand (pH of 4.7 and moisture equivalent of 6.1). A complete outline of planting and fertilizing techniques through the September 1953 harvest has been presented previously (17). There were 4 replications consisting of 4 liming treatments: (1) dolomite-3,600; (2) hydrated lime-3,400; (3) basic slag-3,600; and (4) gypsum-4,000 pounds per acre. Upon these main plots were superimposed: (1) treatments consisting of 1 and 2 ton applications of rock phosphate per acre and (2) soluble potash at 2 rates in combination with soluble phosphorus. Only the data from the liming treatments are presented. Therefore, each value reported is the average of 16 separate samples. Furthermore, since certain of the sub-plot treatments resulted in sub-maximum yields, the yield data would represent lower values than would be expected if the fertility status of the soil had been maintained at an optimum for all sub-plots. Chro-

[3]The cooperation of Climax Molybdenum Co. is gratefully acknowledged for a grant-in-aid which assisted in conducting part of this work.

nology of data important to the experiment were: 1. December 30, 1953—Magnesium sulfate and ammonium molybdate were applied to all gypsum plots at 25 and 1⅓ pounds per acre, respectively.

2. February 2, 1954—The entire area received borax and wettable sulfur at 2 and 10 pounds per acre, respectively.

3. Three of the four sub-plots from each main plot received muriate of potash on February 10, June 1, and October 16, 1954. The remaining sub-plot did not receive fertilizer until 1957 (except for an initial application in 1952).

4. No yields were obtained in the period between April 1, 1955 and June 11, 1957. In the fall of 1955 and 1956 the experimental area was mowed and burned.

5. May 2, 1957—The rock phosphate sub-plots received 200 pounds per acre of muriate of potash, and the 2 soluble potash plots received 500 pounds per acre of 0-8-24, plus 1% each of CuO, MnO, ZnO, and B_2O_3.

Yield data are reported in Table 1. They indicate the inferiority of the gypsum treatment and the superiority of the basic slag treatment. Dolomite generally was superior to hydrated lime, although one of the hydrated lime replicates was located on a dryer spot in the experimental area. Yields from this plot were generally lower (3 to 4 times) than those from the other replicates. In 8 of the 11 clippings no significant differences existed between dolomite and basic slag treatments, although average yields for the 11 clippings showed that basic slag was better.

Soil pH, calcium, and magnesium are presented in Table 2. Gypsum treatments resulted in extremely low soil pH. The slight pH increase in 1957 undoubtedly resulted from burning in 1955 and 1956. The pH of the basic slag treated soil was significantly less than for hydrated lime and dolomite, except in 1957. PH for the hydrated lime and dolomite plots were the same, as were the calcium levels of the dolomite and the basic slag plots. Soil calcium contents for hydrated lime plots were higher, and for gypsum lower, than those of dolomite and basic slag plots. Soil magnesium contents were larger when dolomite was applied, the same for the hydrated lime and basic slag, and lower for gypsum treatments. Examination of these data does not explain why the basic slag treatment usually produced larger yields than other treatments. Re-evaluation of the data on a sub-plot basis indicated that phosphorus, iron, manganese, and copper were not limiting growth on the dolomite or hydrated lime plots, (17).

2. *Lime Requirements of White Clover Following Tomatoes*—Applications of: (1) 0 lime, (2) dolomite-3,000; (3) dolomite-6,000; (4) basic slag-3,500; (5) hydrated lime-2,400; (6) dolomite-1,500 + hydrated lime-1,200; and (7) basic slag-1,750 + hydrated lime-1,200 pounds per acre were disked into a virgin Immokalee fine sand on October 18, 1953. Four additional replications were similarly treated on December 9. The original soil pH was 4.8, with soil calcium and magnesium contents of 60 and 40 pounds per acre, respectively, and a moisture equivalent range from 5.1 to 6.0. Following a spring crop

TABLE 1.—Yields of Pangolagrass-Louisiana White Clover as Affected by Various Liming Treatments.

Treatment	Yields—Pounds Per Acre[1]											
material-lbs./A	3-23-53	5-21-53	7-10-53	9-22-53	3-19-54	5-20-54	7-14-54	11-4-54	4-1-55	6-14-57	10-7-57	Avg.
1. Dolomite-3600	1400	1250	2550	1750	1040	1570	1660	2380	900	2250	4490	1930
2. Hydrated Lime-3400	1080	1000	2050	1650	810	1250	1290	2030	670	2350	4440	1690
3. Basic Slag-3600	1600	1400	2800	2050	1330	1650	1790	2500	1180	3170	6180	2330
4. Gypsum-4000	430	450	1800	1300	590	700	950	1430	530	1500	3790	1230
L.S.D. .05	720	500	550	150	410	510	360	400	N.S.	840	N.S.	220
L.S.D. .01	N.S.	N.S.	N.S.	N.S.	N.S.	730	520	570	-----	1200	-----	300

[1]Average of 4 replications, with 4 clippings and weights obtained from each replicate. (Average of 16 separate samples).

TABLE 2.—Periodic Soil pH, and Calcium and Magnesium Contents as Affected by Various Liming Treatments.

Treatment[1]	pH				Calcium				Magnesium			
materials—lbs./A	12-31-53	4-8-54	1-25-55	4-22-57	12-31-53	4-8-54	1-25-55	4-22-57	12-31-53	4-8-54	1-25-55	4-22-57
					pounds per acre				pounds per acre			
1. Dolomite-3600	5.93	5.70	5.40	5.39	512	565	439	442	257	285	177	139
2. Hydrated Lime-3400	5.98	5.75	5.43	5.33	768	945	624	568	111	96	76	58
3. Basic Slag-3600	5.58	5.20	5.01	5.11	525	595	411	428	123	110	83	67
4. Gypsum-4000	4.88	4.60	4.57	4.76	367	420	311	347	68	35	35	38
L.S.D. .05	0.39	0.42	0.31	0.41	31	120	50	75	25	40	26	17
L.S.D. .01	0.56	0.60	0.44	N.S.	44	175	72	107	36	55	35	24

[1]Average of 4 replications, with 4 separate soil samples analyzed from each replicate. (Average of 16 separate samples).

TABLE 3.—The Effects of Various Liming Treatments Applied to Tomatoes on the Subsequent Yields of Louisiana White Clover—Pangolagrass Mixtures.

Treatment	Dry Weight Yields[2]—Pounds Per Acre									
material-rate/A.	4-22-55	6-17-55	8-11-55	3-29-56	5-22-56	8-1-56	1-7-57	5-15-57	6-11-57	9-9-57	Avg.[3]
1. Check	360	840	1510	520	380	3570	1270	320	1440	2690	1210
2. Dolomite—3000	3300	2440	2510	1860	1160	3450	2070	960	2640	4190	2380
3. Dolomite—6000	3890	3190	2850	2140	1710	3880	3000	1280	3230	5310	2800
4. Basic Slag—3500	3260	2440	2600	2090	1880	3890	2280	870	2520	4200	2690
5. Hydrated Lime—2400	3650	2810	2710	1940	1400	3350	2220	870	2800	4580	2400
6. Dolomite—1500	3290	2250	2480	1740	1080	3090	2170	710	2560	4320	2300
Hydrated Lime-1200											
7. Basic Slag—1750	3740	2860	2630	2240	1810	3900	2230	1490	2560	5250	2810
Hydrated Lime—1200											
Hi-Calcic Lime[1]—4000											
Average	3070	2410	2470	1790	1350	3140	2200	930	2530	4360	2370
L.S.D. .05	680	650	450	580	470	N.S.	710	440	500	680	326
L.S.D. .01	910	880	600	760	620		930	580	660	910	436

[1]Two tons hi-calcic lime applied to treatment 7 plots on August 28, 1956.
[2]Average of 8 replications.
[3]Average yield per clipping date.

TABLE 4.—Chemical Analyses of Soil and Louisiana White Clover as Influenced by Various Liming Treatments.

Treatment[1]	Soil Analyses[2]							
material-rate/A.	pH				calcium-pounds per acre			
	1-5-54	2-16-55	4-6-56	3-12-57	1-5-54	2-16-55	4-6-56	3-12-57
1. Check	4.7	4.5	4.4	5.0	110	120	120	170
2. Dolomite-3000	5.9	5.6	5.0	5.4	480	280	280	250
3. Dolomite-6000	6.2	6.1	5.8	6.0	740	430	480	450
4. Basic Slag-3500	5.6	5.4	5.0	5.5	610	360	350	340
5. Hydrated Lime-2400	6.7	6.0	5.2	5.6	1000	540	480	500
6. Dolomite-1500 Hydrated Lime-1200	6.1	5.9	5.1	5.7	770	440	370	370
7. Basic Slag-1750 Hydrated Lime-1200 Hi-calcic Lime-4000	6.2	5.7	5.1	5.9	890	460	400	1210
L.S.D. .05	0.3	0.3	0.2	0.2	191	75	70	200
L.S.D. .01	0.4	0.4	0.3	0.3	256	100	90	250

Treatment[1] material-rate/A.	Soil Analyses[2] magnesium-pounds per acre 1-5-54	2-16-55	4-6-56	3-12-57	Plant Analyses[2, 3] Ca %	Mg %	K %	P %	Na %	B ppm
1. Check	70	40	60	50	0.64[4]	0.59[4]	2.96[4]	0.210[4]	0.13[4]	53[4]
2. Dolomite-3000	350	170	180	80	1.16	0.66	2.14	0.189	0.38	43
3. Dolomite-6000	560	270	300	180	1.09	0.71	2.24	0.176	0.31	45
4. Basic Slag-3500	150	70	90	90	1.38	0.52	1.78	0.277	0.62	45
5. Hydrated Lime-2400	140	80	90	70	1.72	0.46	1.96	0.179	0.38	49
6. Dolomite-1500 Hydrated Lime-1200	300	140	130	80	1.41	0.58	2.13	0.191	0.35	50
7. Basic Slag-1750 Hydrated Lime-1200 Hi-Calcic Lime-4000	160	80	90	80	1.53	0.55	1.82	0.254	0.49	44
L.S.D. .05	120	35	30	40	0.10	0.05	0.34	0.017	0.12	N.S.
L.S.D. .01	160	45	40	55	0.14	0.07	0.47	0.023	0.16	—

[1]Lime treatments applied to 4 replications each on October 8 and December 9, 1953. Two tons hi-calcic lime applied to treatment 7 plots on August 28, 1956.

[2]Average of 8 replications.

[3]Samples obtained May 7, 1956.

[4]Average of 4 replications because of insufficient plant material; not included in statistical analyses.

of tomatoes that received 2,500 pounds per acre of 4-8-8 fertilizer containing 2.0% MgO, 0.4% MnO, 0.3% CuO, 0.3% Fe_2O_3, 0.2% ZnO and 0.15% B_2O_3, pangolagrass was planted. The area was then mowed, burned, disked, and seeded to Louisiana white clover in early November, 1954. Five hundred pounds of 0-8-24 fertilizer was applied on December 23, 1954, and January 14, 1957, and 0-8-24 plus 1% CuO, MnO, ZnO and B_2O_3 at the same rate was applied May 29, 1956, and April 25, 1957. Muriate of potash was applied at 150 pounds per acre March 17, 1955. The area was burned on December 10, 1955 and October 22, 1956. Two tons of hi-calcic limestone were applied to treatment 7 plots on August 28, 1956.

Yield data are presented in Table 3 and soil and plant analyses are reported in Table 4. The low production from the check plots was obvious. Soil pH was 5.0 and below, and calcium and magnesium contents were less than 170 and 70 pounds per acre, respectively. There was equal production of forage in August 1955 and 1956 from all but the check plots. In September 1957, however, superior yields were obtained from the 6,000 pound dolomite plots and the plots receiving the 4,000 pound rate of hi-calcic limestone in August 1956. Average yields showed that applications of 6,000 pounds of dolomite, and the basic slag—hydrated lime—hi-calcic lime combination were better than the 3,000 pound dolomite, the dolomite-hydrated lime combination and the 2,400 pound hydrated lime treatments. Basic slag applied at a rate of 3,500 pounds was in an intermediate position. The soil analyses from the three better treatments (numbers 3, 4, and 7) showed pH and calcium and magnesium values to be above 5.0 and 340 and 70 pounds per acre, respectively; and they were above 5.0, and 250 and 80 pounds per acre, respectively, for the poor treatments (numbers 2, 5, and 6). These data suggest that calcium and magnesium levels in the soil above 340 and 70 pounds per acre, respectively, will result in maximum Louisiana white clover-pangolagrass growth following a crop of tomatoes.

Clover samples obtained May 7, 1956 were analyzed for various elements. Calcium and magnesium contents varied considerably but generally were consistent with soil contents. Although potash was applied uniformly, potassium contents were usually higher when the calcium contents were lower and sodium contents were lower when potassium contents were higher. Phosphorus contents were higher in clover on plots receiving basic slag. Liming had no effect on the boron content of white clover.

3. Greenhouse Experiments—In the two studies reported, both commercial hi-calcic limestone and 500 pounds per acre 0-8-24 fertilizer containing 1.0% each of CuO, MnO, ZnO, and B_2O_3 were used. Both were mixed thoroughly with the entire soil mass in the pots, except for certain treatments which consisted of sprinkling the lime over the seed at a rate of 200 pounds per acre. Louisiana S-1 white clover seed was placed in the pots in a circular pattern, in a row, approximately equal distance from the center and the sides of the pots. Pots were watered uniformly with distilled water to provide adequate soil moisture.

In the first experiment equal volumes of virgin Immokalee fine sand, having a soil pH of 5.3, and calcium, magnesium, phosphorus, and potassium contents of 50, 10, 1, and 10 pounds per acre, respectively, were placed in twenty-eight 2-gallon pots. Treatments of lime at rates in pounds per acre were: (1) 0; (2) 200 mixed with the seed; (3) 500; (4) 1,000; (5) 1,500; (6) 2,000 and (7) 200 mixed with seed that had been inoculated with *Rhizobium* bacteria. The experiment was designed to determine the calcium requirements of white clover. With the exception of treatment 7, all pots received C.P. grade ammonium nitrate at a rate of 300 pounds per acre. This was done to circumvent possible interaction effects between the lime requirements of the bacteria and the lime requirements of the clover plants per se. Several days after fertilization, on May 31, 1957, all pots were seeded. The seed had been soaked for about 10 minutes in a 60 ppm solution of sodium molybdate prior to planting. On July 19 all pots received ammonium nitrate at a rate of 150 pounds per acre, and clover from all pots was clipped on July 23. Re-growth was permitted and all pots were re-fertilized with the same mixture and at the same rate on September 20. Soon after, however, plants were observed being damaged by some type of soil-borne disease. Because of this, it was decided to discontinue the experiment. Soil samples were taken on October 3.

Soil analyses and yields are reported in Table 5. Yields resulting from rates of 1,000, 1,500 and 2,000 pounds of hi-calcic limestone per acre were the same, and all were larger than those from other treatments. There was no significant difference in yield when 0, 200, and 500 pounds were applied. Yields from treatment 7, where seed was inoculated and 200 pounds of hi-calcic lime was applied over the seed, were larger than the same treatment without seed inoculation.

TABLE 5.—The Effects of Various Rates of Hi-Calcic Limestone on the Yield of Louisiana S-1 White Clover Growing in the Greenhouse and on the Soil pH, and Calcium and Magnesium Contents.

Treatment[1]	Soil Analyses[2]			Dry Weight Yields[2]
rate-lbs./A.	pH	Ca	Mg	gm./pot
1. 0	4.35	14	22	1.15
2. 0 + 200 mixed with seed	4.31	19	21	1.50
3. 500	4.23	121	38	2.20
4. 1000	4.51	175	37	4.23
5. 1500	4.76	306	43	4.13
6. 2000	5.28	450	40	4.95
7. 0 + 200 mixed with inoculated seed	4.16	15	21	2.80
L.S.D. .05	0.39	91	12	1.21
L.S.D. .01	0.53	124	16	1.65

[1]The virgin soil pH was 5.3, while soil contents of Ca, Mg, P, and K were 50, 10, 1 and 10 pounds per acre, respectively. Only seed planted in treatment 7 was inoculated. Adequate nitrogen was applied to other treatments to insure maximum clover growth. All pots were seeded on May 31, 1957.

[2]Average of 4 replications, harvested July 23, 1957.

Maximum yields were obtained when the soil pH was 4.51 and calcium and magnesium contents were 175 and 37 pounds per acre, respectively. Reduction of clover growth by approximately 35% was obtained when the soil pH was 4.16, and calcium and magnesium contents were 15 and 21 pounds per acre, respectively. The calcium level was considerably less than those reported in the previous sections as being necessary for maximum growth. It should be remembered however, that the soil tests indicated only the residual soil status.

In the second study, in 1-gallon pots, 4 soils having different moisture equivalents, pH, and calcium levels were treated with various rates of lime in duplicate. Soils A, B, and C had received field applications of 1 ton of hi-calcic limestone per acre several months previously. In addition, soil C had received one ton of rock phosphate per acre. Soil D was virgin. The mosture equivalent of these soils ranged from low (4.0) to rather high (22.8).

The lime treatments were as follows: (1) 0; (2) 200-mixed with seed; (3) 1,000; (4) 1,000 + 200-mixed with seed; and (5) 3,000 pounds per acre. Inoculated seed was planted immediately after fertilization and liming on May 16, 1957. Clippings were made on June 25 and July 23, and soil samples were collected on the latter date.

Yields and soil analyses of all lime treatments were averaged and the effects of soil types are reported in Table 6. Soil B, probably because of poor aeration, resulted in the poorest yield, even though soil pH, calcium, and magnesium were adequate. Equal yields were obtained when: soil pH values were 4.7, 5.4, and 6.2; calcium contents were 570, 1093, and 1273; and magnesium contents were 88, 212, and 288. Although data were also calculated on a basis of the lime treatments (averages based on lime treatments regardless of soil type), they are not presented here because yields were not significantly different. Clover did not respond to applications of lime, even when in soil D, which had original soil calcium and magnesium contents of 210 and 51 pounds per acre, respectively. Scatter diagrams were made to determine if yield data and soil pH or calcium contents were as-

TABLE 6.—The Effects of Various Soils on Soil Analyses and Yields of Louisiana S-1 White Clover Grown in the Greenhouse

Soil	Original Soil Analyses				Soil Analyses after treatment[2]			Dry Weight Yields[2]
	M.E[1] %	pH	Ca -lbs./A-	Mg	pH	Ca -lbs./A-	Mg	gm./pot
A	8.1	5.7	1000	189	6.23	1273	212	1.47
B	22.8	5.6	2400	330+	5.99	2243	627	0.98
C	8.2	4.9	950	245	4.67	1093	288	1.44
D	4.0	5.4	210	51	5.37	570	88	1.53
L.S.D. .05	—	—	—	—	0.14	87	16	0.43
L.S.D. .01	—	—	—	—	0.19	120	22	N.S.

[1]Moisture equivalent.

[2]Soil samples were collected on July 23 and yields were averages based on clippings made June 25 and July 23. All data are averages of ten pots.

sociated. Individual yields and soil analyses from each pot were used to plot the points. Because of the small number of observations, regression coefficients were not calculated. Even though soil pH and calcium contents were in ranges from 4.5 to 6.5 and 200 and 2,700 pounds per acre, respectively, observed yield trends were lacking.

DISCUSSION

White clover growth on Immokalee fine sand has been shown to be affected by soil conditions associated with low pH and calcium contents. These associations, in certain instances, however, were not clearly defined. In the first experiment maximum clover-pangolagrass yields were obtained on basic slag plots with soil pH values of 5.0 to 5.2, calcium contents of 411 to 595 and magnesium contents of 67 to 123 pounds per acre. Dolomite plots, however, had comparable values of 5.4 to 5.9, 439 to 565, and 139 to 285, respectively; values for hydrated lime plots were 5.3 to 6.0, 568 to 945, and 58 to 111, respectively, and gypsum plot values were 4.6 to 4.9, 311 to 420, and 35 to 68, respectively. Undoubtedly, some factor (s) other than pH, calcium or magnesium influenced the clover-grass yields. Based on results of the other experiments, the soil from the gypsum plots contained sufficient calcium to produce better clover growth than that obtained during this experiment. In the fall of 1953, there was no live-over clover on the gypsum plots, but seed sown in October 1953 (to insure a more uniform stand) appeared to have a normal color in January 1954. Clover growth in certain of the gypsum sub-plots, particularly those that had received sufficient phosphorus and potash, continued to improve. Gradual encroachment of clover into certain of the gypsum plots was observed. The reason for this was not clear, but soil tests did not indicate that lime from adjoining plots had washed into the gypsum plots. Soil pH values for certain of these individual plots were found to be as low as 4.3, and soil calcium and magnesium contents were 190 and 20 pounds per acre, respectively. The average yield of 11 clipping from one such plot was 2,100 pounds per acre, while a comparable yield for the average of the basic slag plots was approximately 2,300 pounds per acre. Although the reasons for the excellent growth on certain of the gypsum plots are not known, it was evident that white clover would grow well when soil pH values were below 5.0, even when calcium and magnesium contents were below 300 and 50 pounds per acre, respectively.

In the test following tomatoes, maximum yields were obtained with average calcium levels of about 350 pounds per acre and pH values of 5.0 to 5.6. Magnesium contents were below 100. However, certain of the poorer yielding treatments also had values equal to, or higher than, these. This is further evidence that maximum yields would be obtained with soil pH and calcium and magnesium contents above certain levels, only if other factor (s) were optimum.

It was apparent from greenhouse results that the calcium levels must be approximately 200 pounds per acre to insure the maximum production of one crop of clover. Soil type and moisture also appeared to be influential in clover production.

All these results and observations indicate that on established clover-grass pastures (flatwoods soil), there would be no response to additions of lime when soil pH was above 5.0 and calcium and magnesium values were above 400 and 75 pounds per acre, respectively. These values might also be adequate on newly planted clover, provided normal nodulation occurred. This can be assured only if sufficient calcium is present in the soil solution to provide optimum conditions for root infection by the bacteria. Australian research workers have solved this problem by drilling small quantities of lime or ammoniated superphosphate with the seed or by using lime-pelleted seed. From other greenhouse studies, not presented here, results of lime treatments to seed planted on flatwoods soil have not been conclusive.

CONCLUSIONS

1. Maximum yields of clover-pangolagrass mixtures in one field experiment were obtained when soil pH, and calcium and magnesium values were above 5.0, and 411 and 67 pounds per acre, respectively.
2. In the second field experiment clover-pangolagrass produced more forage when soil pH, and calcium and magnesium values, were 5.0, and 340 and 70 pounds per acre, respectively.
3. One greenhouse test showed that maximum clover yields were obtained when soil pH, and calcium and magnesium values, were 4.5, and 175 and 37 pounds per acre, respectively.
4. No response from established clover-grass pastures growing on flatwood soils would be expected if soil pH, and calcium and magnesium values, were above 5.0 and 400 and 75 pounds per acre, respectively.

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Some Plant Responses and Soil Changes Resulting From Controlled pH Levels in Experiments with Cigar-Wrapper Tobacco[1]

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The importance of soil pH to the production of shade-grown cigar-wrapper tobacco has not been thoroughly investigated. Results obtained at the North Florida Experiment Station, Quincy, (5, 6) and the data of Irvine and Valleau (4) indicated that incidence of the disease blackshank (*Phytophthora parasitica* var. *nicotianae* (Breda de Haan) Tucker) varied directly with soil pH. Anderson *et al* (1) reported an undesirable brick-red ash color was produced when the soil used for cigar-wrapper tobacco was extremely acid. Other disease and quality factors in cigar-wrapper tobacco have not been studied intensively in relationship to soil pH. The purpose of this experiment is to investigate further the effects of soil pH variations on disease, quality and yield of cigar-wrapper tobacco as well as to study the effects of these pH levels on the soil itself.

EXPERIMENTAL

This experiment was conducted in a shade at the North Florida Experiment Station on an area of blackshank-infested Marlboro fine sandy loam. Blackshank-resistant varieties of shade tobacco had been grown on this soil for the preceding four years. The area was divided into 16- by 32-foot plots with five treatments in quadruplicate arranged in a randomixed block design. Rates of dusting sulfur, 93%, or commercial hydrated lime were broadcast and then mixed with the top 7 to 8 inches of soil with a rotary tiller, December 18, 1953. These rates of sulfur and hydrated lime were varied to provide a pH range of from about 4.5 to 6.2 for the five treatments during the first crop season. Annual adjustments were made when necessary to maintain the soil pH at the desired levels. Fertilization of the first crop was as follows: 11 tons per acre of stable manure broadcast and harrowed in January followed by 2,700 pounds per acre of fertilizer consisting of 1,600 lbs. of cottonseed meal (41% protein), 100 lbs. Nugreen, 300 lbs. steamed bone meal, 100 lbs. superphosphate, 100 lbs. nitrate of soda, 300 lbs. of potassium sulfate and 200 lbs. of dolomite. About 60% of the fertilizer was applied in the drill in March prior to transplanting, the remainder was applied in two equal amounts as side-dressing about one and two weeks after transplanting. The fertilization of succeeding crops varied somewhat from year to year with availability of materials but not enough to be a factor in this experiment.

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One test row in each plot was fumigated each February using Dowfume W-40 at 15 to 17 gallons per acre broadcast to a depth of 6 inches and planted to Dixie shade in 1954, Rg in 1955 and 1956, and Magnolia in 1957. The other test row remained unfumigated and was planted to Dixie shade each year. The Dixie shade variety is highly resistant to blackshank, moderately resistant to root knot, and highly susceptible to coarse root; Rg is resistant to blackshank but susceptible to root knot and coarse root; Magnolia is highly resistant to blackshank, susceptible to root knot and moderately susceptible to coarse root.

RESULTS AND DISCUSSION

The incidence of blackshank increased directly with increasing soil pH (5) the first year of the experiment; the same observations were made for three additional years. On the other hand, the incidence of root knot (*Meloidogyne* sp.) and of coarse root (*Pratylenchus* sp. and others) varied inversely with soil pH (6). Differences were significant, especially on the 1956 crop. Although bacterial and fungous diseases of plants have long been correlated with soil pH differences, few if any correlations between soil pH and nematode infestations have been reported. The data summarized in Table 1 obtained from soil samples taken from the unfumigated area of each plot is admittedly of a preliminary nature but tends to confirm an inverse response of nematodes to increasing soil pH.

TABLE 1.—Average Number of Parasitic Nematodes (Primarily Rotylenchus Sp.) Per 150 Ml. Moist Soil Taken May 17, 1957 From Shade Tobacco Soil pH Plots. Examined by W. H. Thames.

Soil Treatment	Soil pH (Ave. 4 plots)	Parasitic Nematodes (Ave. of 8 samples)
T1	5.06	13
T2	5.53	11
T3	5.78	9
T4	5.97	6
T5	6.28	5

The maintenance of an exact pH level in a soil receiving the heavy fertilization used here would be an impossible task. Five distinct soil pH range areas were maintained but it must be understood that the pH values were not static. The most acid soils, maintained by sulfur treatment, had the greatest range of variability. The initial acids formed by the sulfur lowered the pH very sharply but succeeding leaching rains moved these acids and soluble salts down the soil profile, permitting the surface soil to approach the pre-treatment pH. Less fluctuation was observed on the hydrated lime-treated plots. In addition, all plots showed the usual decrease of from 0.1 to 0.4 of a pH unit resulting from the temporary soil acids produced by the fertilizer (2). In 1956 the pH correctional treatments were applied in the early fall with the result that the acids were leached from the soil before the tobacco was planted. The acid soil treatments had considerably

higher pH values than those intended for that season. The nature of these pH fluctuations explains why the soil pH for any given treatment is not the same in each table of data.

Some effects on the soil after four years of controlled variation in soil pH are shown in Table 2. The increase in exchangeable calcium follows the increase in soil pH as would be expected from the additions of hydrated lime. To a lesser extent exchangeable magnesium follows the same pattern indicating the possibility of a small amount of magnesium in the lime. Lime increased the retention of exchangeable potassium as shown by the potassium values.

The effect of increased acidity on the exchangeable aluminum is probably less drastic than could be expected on the average Florida soil. Heavy applications of organic matter and large reserves of phosphate from continued high rates of fertilization have probably reduced the mobility of aluminum in the soil to the point where large quantities of aluminum do not become soluble or readily move onto the exchange complex under conditions of increased acidity.

The manganese values in Table 2 are of particular interest. It is evident that a considerable loss of total manganese has occurred in the acid plots. This loss is several times as great as any losses that could be attributed to removal by the crop. Normally increased soil acidity increases the soluble (easily reducible) manganese (3) and it is assumed that this is what occurred here. Increased solubility accellerates the rate of leaching resulting in the loss of total manganese from the soil. The reduction in the easily reducible manganese shown at the low pH values is attributed to the reduced total manganese supply and the increased rate of manganese uptake by the tobacco plant in the absence of other competing bases. Although there was some indication the first year that soil fumigation increased the availability of manganese, this was not borne out in later years. All of the data in Table 2 represent a composite from fumigated and unfumigated plots; no significant differences resulting from fumigation were observed in the separate soil analyses.

Mineral analyses of the combined leaf and stem as harvested in the field are given in Table 3. Analyses were made from the second, fourth and sixth primings of each crop. Data for the fourth priming are omitted, since the results were intermediate to those reported. The later primings tend to be higher in nitrogen and calcium and lower in potassium than the earlier ones. The higher potassium in the late priming on the limed plots reflects a higher reserve of this element in the limed soils. A high potassium to calcium ratio in the most acid plots results in a high potassium uptake from these plots in the early primings. The higher nitrogen levels in late primings on the acid plots probably indicates a slower rate of nitrification. The manganese content of the leaves varies inversely with soil pH. This relationship produces a very highly significant linear correlation when soil pH is plotted against the log of the manganese content expressed as parts per million (Fig. 1). Since manganese levels in the leaves in excess of 350 ppm. of Mn (1) causes an undesirable brick-red ash color, the maximum soil acidity permissible without danger of producing off quality tobacco because of excessive manganese would be pH 5.1 for this soil type.

TABLE 2.—Analysis of Soil Samples of Marlboro Fine Sandy Loam After Growing Four Crops of Cigar-Wrapper Tobacco at 5 pH Levels.

Soil Treatment	Soil pH			Exchangeable Bases* lbs./Acre			P_2O_5* lbs./acre	Exch. Al* ppm	Mn lbs./acre (3)** Total	Easily Reducible
	1-30-57	4-1-57	5-27-57	CaO	K_2O	MgO				
T1	4.46	4.75	5.10	513	434	146	124	10.6	59	29
T2	4.92	5.29	5.53	562	517	177	117	9.3	67	40
T3	5.52	5.75	5.82	763	626	205	109	8.5	79	51
T4	5.84	5.91	5.98	778	672	191	119	8.3	82	50
T5	6.18	6.26	6.29	1045	680	226	126	6.5	75	46

*Extracted with N NH_4Ac sol'n. pH 4.8.

**Number cited in parentheses refers to literature cited.

TABLE 3.—Mineral Analysis of Cigar-Wrapper Tobacco Grown in 1957 on Marlbobo Fine Sandy Loam at 5 pH Levels.

Soil Treatment	N %	K %	Ca %	Mg %	Mn ppm
Priming No. 2					
T1	2.78	8.16	1.28	0.48	629
T2	2.69	7.74	1.26	.49	253
T3	2.70	7.97	1.09	.50	180
T4	2.53	7.83	1.25	.47	140
T5	2.59	7.89	1.33	.45	113
Priming No. 6					
T1	3.71	4.80	2.18	.49	730
T2	3.42	5.21	2.01	.54	302
T3	3.23	5.45	1.83	.49	181
T4	3.37	5.11	2.25	.51	150
T5	3.18	5.25	2.21	.47	105

At the start of this experiment it was anticipated that there would be a sharp reduction in the rate of nitrification in the soils at the lowest pH. These differences did not prove to be as large as first anticipated, Table 4. Similar data collected in subsequent years generally proved to be nonsignificant. It may be assumed that the large application of manure and cottonseed meal served to overcome part of the detrimental effect of low soil pH on nitrification (7). Higher nitrogen levels in the leaves of late primings from the more acid plots may indicate reduced nitrification on these plots, since excess nitrates produced very early in the season may have been leached out before they could be utilized by the plant.

Yield and quality measurements have not been completed. In general, the best quality, as measured by grade index, was produced at the third or intermediate soil pH level. The differences between the quality at this level and at the extreme pH levels approached the 5% level of probability. Yield has increased with increasing soil

TABLE 4.—Effect of pH Levels and Soil Fumigation on the Ammonia and Nitrate Nitrogen Found in a Marlboro Fine Sandy Loam. Soil Samples Taken April 23, 1954.

Soil Treatment	Soil pH	ppm Ammonia N		ppm Nitrate N	
		Fum.	Unf.	Fum.	Unf.
T1	4.45	50	36	15	15
T2	4.97	33	30	31	23
T3	5.42	31	33	21	31
T4	5.57	26	22	32	40
T5	6.05	31	19	54	26

Significant correlation coefficients:
pH and ammonia N (fumigated) $-.64 \pm .09$
pH and ammonia N (unfumigated) $-.64 \pm .09$
pH and nitrate N (fumigated) $+.46 \pm .12$
pH and nitrate N (unfumigated) $+.34 \pm .13$

acidity and has generally been significant. As mentioned previously, these increased yields may be associated with a slightly slower rate of nitrification. However, further tests will be necessary before it can be determined whether the yield and quality responses obtained represent direct effects of the soil environment at these pH ranges or indirect effects from soil-borne diseases hindered or favored by changes in soil pH.

SUMMARY

Cigar-wrapper was grown for four seasons on soil at five controlled pH ranges between 4.5 and 6.3. Incidence of blackshank varied directly with soil pH while damage from nematodes varied inversely with increasing soil pH. Yield and quality were influenced by both soil pH levels and the soil-borne diseases. highest quality was usually obtained at the intermediate pH levels with highest yields at the lowest pH range. Manganese levels in the leaves increased in a highly significant manner with increased soil acidity. A similar but less significant trend was noted for nitrogen.

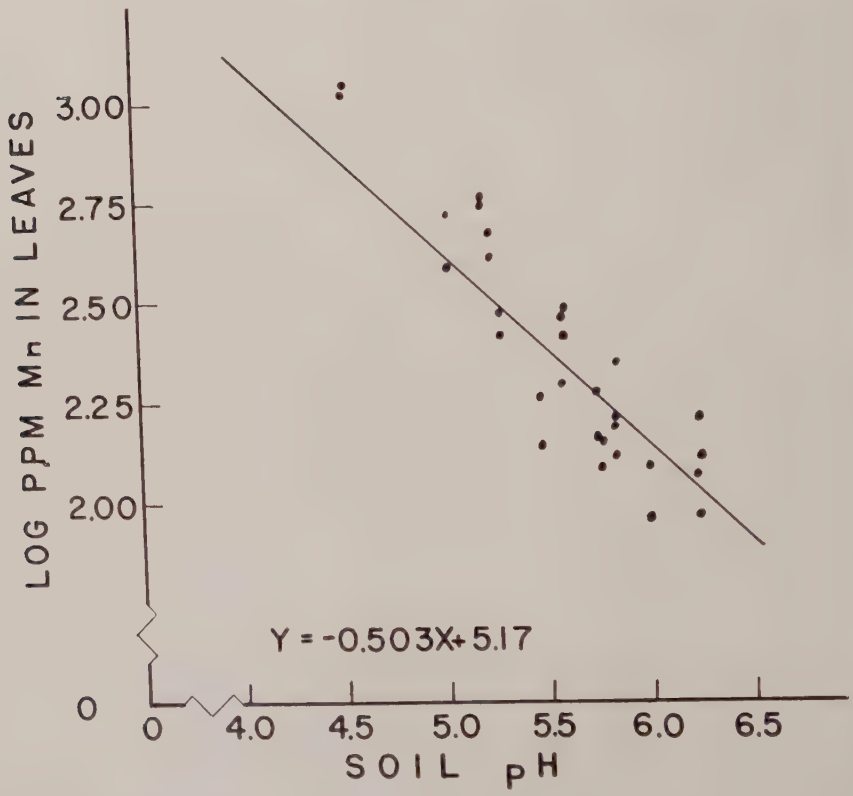

Figure 1.—Relationship between soil pH and manganese content of cigar-wrapper tobacco leaves. Coefficient of correlation $r = .85$. Required r for significance at 1% .46.

In the soil, exchangeable Ca, K and Mg increased with increasing soil pH, while exchangeable Al decreased. Acid ammonium acetate extractable phosphate was very high and did not seem to be influenced by soil treatment. Both total and easily reducible manganese were reduced by continued maintenance of the soil at low pH levels.

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Virus Diseases of Yellow Lupine: Preliminary Investigation on Control By the Use of A Protecting Border[1]

M. K. Corbett and J. R. Edwardson[2]

Lupines have been used extensively throughout the world as cover and/or forage crops. Warner (21) in 1939 released bitter blue lupine (*Lupinus angustifolius* L.) as a potential winter cover and green manure crop for the southeastern United States. Ritchey in 1948 (19) reported on the value of sweet selections of blue, white (*L. albus* L.), and yellow (*L. luteus* L.) lupine for winter forage and seed crops. The monetary value of this crop to the farmer is difficult to determine, although it represents one of the best winter cover and forage crops grown in the Southeast. The production of sweet yellow lupine has been hindered by a virus disease which greatly curtails the amount of seed set. The resulting low seed yield has increased the cost of seed, thus prohibiting extensive use of this crop for forage.

Several viruses have been reported as causing diseases of lupines. Neill et al. (16) in 1934 described a virus disease of blue lupines in New Zealand; they termed the disease sore-shin. Chamberlain (5), working on the same disease, attributed its cause to infection by pea mosaic virus. Norris (17) reported that the bunchy top disease of *L. varius* L. and the sore-shin disease of blue lupines in Australia were caused by pea mosaic virus. A disease of blue lupine, termed lupine browning and caused by cucumber mosaic virus, has been reported from Germany and New Zealand by several investigators (6, 12, 18). Mastenbroek (13) described a virus disease of yellow lupine in Holland; he attributed it to infection by a previously undescribed virus termed Lupinus virus 1. Weimer (22) reported 2 virus diseases of blue lupine as occurring in epiphytotic form in Georgia during the spring of 1949. Decker (10) in 1950 reported a sap-transmissible virus as occurring in plantings of yellow lupine at Gainesville, Quincy, and Jay, Florida. Recently, this virus has been identified as a strain of bean yellow mosaic virus (BYMV) and shown to be the principal virus disease of blue, yellow and white lupine in the southeastern United States (9).

The symptoms of this disease in blue, yellow, and white lupines have been described in detail elsewhere (8, 9) but will be briefly described here.

Foliage of infected blue lupine plants develops a bronze color and tends to wilt. Necrotic streaks appear on the stem and the apex of the plant often bends over, forming a shepherd's crook. The plant

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eventually dies. These symptoms are similar to those attributed to infection by pea mosaic virus (5, 17).

Yellow lupine plants infected by BYMV develop many leaf deformations, and the new growth exhibits a mottle or mosaic. These symptoms are invariably accompanied by abnormal flower development. Flower parts are usually deformed and pods are rarely set on plants infected early in the growing season. Diseased yellow lupines exhibit symptoms similar to those reported by Mastenbroek (13) for Lupinus virus 1.

Very few white lupines are grown commercially and those that become infected develop a mottle or mosaic and various leaf deformations.

Bean yellow mosaic virus and cucumber mosaic virus are both transmitted by arthropods of the family *Aphidae* (aphids). BYMV is transmitted in the field by at least two species of aphids, *Myzus persicae* (Sulz.) and *Aphis medicaginis* Koch. (9). The virus is transmitted in the typical nonpersistent manner, that is, the aphid can acquire the virus after a relatively short feeding period on a diseased plant and retains the virus for less than one hour. The longest period of retention of the virus was not more than 10 minutes (9); this time may be longer if the aphid is starved rather than fed following acquisition of virus.

The main weed sources of the virus in northern Florida appear to be the sweetclovers, *Melilotus alba* and *M. indica* (9). The virus has a wide host range within the legume family and the only reported cases of this virus occurring outside the *Leguminosae* are several reports of its occurrance in gladiolus (2, 14). The virus is transmitted through approximately 6 per cent of the seed from diseased yellow lupine (9). Thus, the use of infected seed supplies a source of the virus sufficient to cause a field to be almost 100 per cent infected before harvest time. No virus-infected plants occurred in representative seed samples from lots of Weiko III sweet yellow lupine imported from Germany. Of 4721 plants grown from imported seed of the Weiko III variety, none showed symptoms of virus infection nor could virus be recovered from them (9).

The main known facts about this virus may be summarized as follows: 1) the virus is transmitted by aphids in the nonpersistent manner, 2) the main weed sources of the virus are the sweetclovers, 3) the virus is transmitted through the seed of diseased plants, and 4) seed of the Weiko III variety of sweet yellow lupine imported direct from Germany at present represents a source of virus-free seed.

For a virus to spread to any great extent in any crop, there must be present 3 conditions: 1) a source of the virus, 2) a moving vector, and 3) a susceptible crop.

Control of virus diseases in plants may be attained by eliminating or controlling any one of the above 3 conditions. The source of the virus can be removed but this is usually difficult, for the host range of a virus usually is sufficiently wide to enable more than one species of plant to act as the alternate host. Success has been achieved along this line with some viruses and certain crops (11, 23). In the future, specific weed killers undoubtedly will expand this type of virus control in certain crops. Attempts have been made to control the

vectors by the use of insecticides: however, results have been conflicting and not too promising (1). Although all the insect vectors of a virus on a crop may be removed with applications of insecticides, migrant flights of insects are at present impossible to control. Simons (20) reported a significant reduction in virus spread to peppers by spraying the weed source plants rather than the host.

The use of an immune or resistant crop would be the ideal method to follow in controlling virus diseases. This method has been successful against certain viruses with certain crops (7, 4, 15).

At present, control by the elimination of the source plants of BYMV has not been adequately investigated. A usable source of resistance in the genus *Lupinus* has not yet been found. All tested lines of yellow lupine and species of the genus Lupinus are susceptible to the virus except the following 6 perennials: *Lupinus arboreus* Sims., *L. cumulicola* Small, *L. longifolius* Abrams, *L. perennis* L., *L. polyphyllus* Lindl., and *L. villosus* Willd. (9). Successful crosses between these species and the commercial *L. angustifolius*, *L. luteus*, and *L. albus* have not been accomplished.

Control of the vector by a conventional spray program on lupines would appear uneconomical, and the results in terms of disease incidence are doubtful. Simons (20) has reported significantly less spread of virus to peppers when sunflower, an immune plant, was planted between the susceptible pepper crop and the virus weed source.

It appeared possible that planting protective borders of an immune crop around a lupine field planted with virus-free seed might reduce the number of viruliferous aphids entering the lupine field. Although such a procedure might not afford 100 per cent control, it seemed possible that the amount of infection might be less than that in unprotected fields, thus resulting in a satisfactory and profitable seed yield. If such were the case, it might be possible to use seed for several years before the percentage of virus-infected seeds increases to such proportions that it would be advisable to discard all seed and start again with virus-free seed.

To test the above described hypotheses, the following experiments were conducted during 1956-57.

Materials and Methods.—Seed of the Weiko III variety of sweet yellow lupine imported from Germany was used. A sample of 4721 plants was grown from this seed lot and found to be virus free. The lupine plots were ⅛ acre in size. The seed was planted at Gainesville, by hand, at the rate of 60 pounds per acre in 38-inch rows. Two plots were surrounded with an oat border 24 feet wide and 2 plots were not surrounded by oats. The width of the oat border was determined by the amount of land available. Floriland oats were planted at the rate of 2 bushels per acre and fertilized with an 8-8-8 formulation at the rate of 400 pounds per acre. The lupines were fertilized with an 0-12-12 formulation at the rate of 400 pounds per acre. The number of virus infected plants in each plot was obtained by 3 separate counts in each plot during the growing season. The yield data were obtained from random 6-foot samples, containing a representative stand, from each row. Ninety six samples were taken from each plot. Stand counts were obtained by pulling all plants in all plots.

Plots similar to those planted with Weiko III seed were planted with commercial sweet yellow lupine seed. All plots were treated identically with regard to planting, fertilization, harvest, and note taking. The only difference between the plots was that the commercial seed contained approximately 2 to 6 per cent virus-infected seed.

Two replicates of Weiko III and 2 of commercial yellow lupine were planted at Live Oak, Florida, and handled as described for the Gainesville plantings.

After a 1-year exposure, representative seed samples from protected and unprotected plots of Weiko III were tested for the percentage of seeds transmitting the virus. These tests were conducted in screened greenhouses periodically sprayed with parathion.

Results.—The plots at Live Oak, Florida, were severely damaged by cold early in the season; consequently no data were obtained from these plantings.

The plots at Gainesville were planted November 12 and all plots survived the winter with respect to cold damage. Because of adverse growing conditions, mainly lack of moisture, the plants grew poorly. The first reading for number of virus-infected plants was not conducted until the 2nd week of February, with subsequent readings in March and April. All data (percentage of virus-infected plants, yield, and stand counts) were subjected to statistical analysis by the "t" test.

If it is assumed that 2 to 6 per cent of the plants in plots planted with commercial seed were infected as the result of the planting of infected seeds, the number of diseased plants increased in both protected and unprotected plots soon after emergence (Fig. 1). By February, approximately 17 per cent of the plants in both replications of the 2 treatments were infected. By March, the percentage had increased to 95 and by April almost all plants in both the protected and unprotected plots were infected.

The plots planted with Weiko III seed presumably started with virus-free seed. By February, less than 1 per cent of the plants in the protected plots were infected by virus. In the unprotected plots, read at the same time, approximately 4 per cent of the plants were virus-infected. By March, the percentage of virus-infected plants in the protected and unprotected plots had increased to 4 and 8 respectively. The last reading, made in April, showed an increase in the percentage of virus-infected plants from 4 to 13 in the protected plots and from 18 to 99 in the unprotected plots.

The average yields (in pounds per acre) obtained from the different plots (Fig. 1) are as follows: Weiko III protected, 820.9; Weiko III unprotected, 430.3; commercial seed protected, 86.5; and commercial seed unprotected, 120.7. The yield differences were highly significant at the 1 per cent level in the following cases: Weiko III protected vs. Weiko III unprotected; Weiko III protected vs. commercial protected; Weiko III unprotected vs. commercial unprotected. All other yield differences were not statistically significant except commercial protected plot 2 vs. commercial protected plot 1. This difference is attributed to plot location. A negative correlation coefficient of -0.942 was obtained for yield vs. number of virus-infected plants. Differences in stand were not statistically significant except

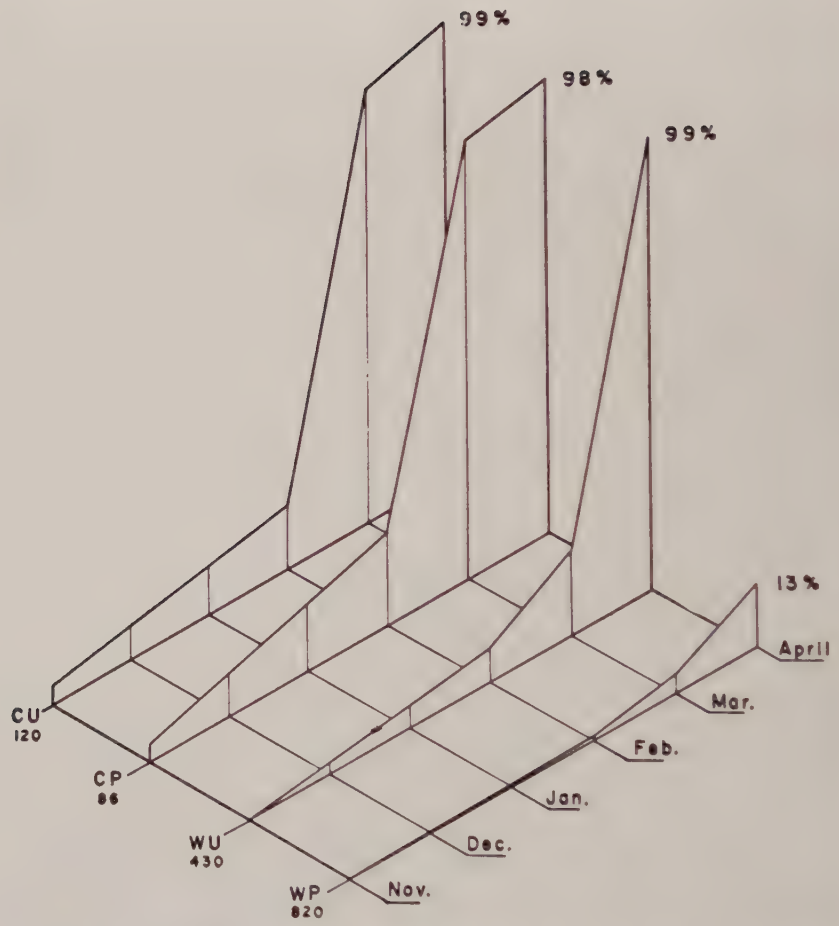

Figure 1.—Percentage of plants infected and yield obtained from protected and unprotected plots of Weiko III and Commercial Sweet Yellow Lupine. Data represents the average of two replicates for each treatment. W—Weiko III seed, C—Commercial seed, P—protected, U—unprotected. Yields 820, 430, 86 and 120 in pounds per acre.

Weiko III protected vs. commercial protected. The correlation coefficient for yield on stand was not significant. Differences in number of virus-infected plants were not significant, with one exception: the difference between the number of virus-infected plants in the Weiko III protected plots and that in each other treatment was highly significant. A highly significant correlation coefficient of +0.917 was found for the comparison of virus infection with stand.

A total of 5433 plants were grown from a representative seed sample from the Weiko III protected plots. Fifty-one, or 0.94 per cent, of these plants had symptoms typical of virus infection. From the 4651 plants grown from seed of the unprotected plots of Weiko

III, 104, or 2.2 per cent, contained virus that resulted from transmission through the seed. A direct association between treatment and the number of virus-infected plants resulting from seed transmission is indicated by the X^2 test for independence. A probability of less than 0.01 was found for the assumption of no association.

DISCUSSION.—The significantly larger yield obtained from the protected plots of Weiko III (virus-free seed) than that from the unprotected plots of the same seed may be attributed to the protecting border of 24 feet of oats. Although the oat border made poor growth it must have reduced the numbers of viruliferous aphids that entered the field. It appears probable, however, that the oat border had little or no effect on the total number of aphids entering the plots, since there was approximately the same amount of secondary spread in the plots planted with commercial seed. Supposedly, many of the incoming aphids first landed on the oats and fed there for a short time at least. Since BYMV is nonpersistent in the aphid, it is reasonable to suppose that many of the aphids became nonviruliferous before they moved onto the lupine.

Protection by an immune crop in the case of seed plots planted with commercial seed fails because virus is already present in the plot.

In the unprotected plots of virus-free seed, the largest number of virus-infected plants occurred near the edges of the plots. Almost all plants throughout the plots became infected by the end of the growing season. The pattern of virus entry into the protected plots could not be correlated with any particular part of the field; infected plants occurred at random throughout the field. Infection did not occur as fast and the spread was not as extensive in the protected plots as in the unprotected ones. This pattern of spread in the protected plots also suggests a protective effect of the oat border. If viruliferous aphids had entered freely, then infected plants should have been more numerous at the field edge than in the interior. That the border was not completely effective is illustrated by the facts that virus-infected plants were found in the protected plots and the virus was subsequently transmitted to neighboring plants.

Only by continuing these tests for a number of years can it be determined whether or not seed from protected plots planted with virus-free seed can be used for several years. It is possible that the small percentage of infected seed (0.94%) might be sufficient to provide inoculum for extensive spread the next year. This will depend upon many factors, including the number of moving vectors. This phase of the work is still in progress.

Although the present results indicate that a protective border can effectively reduce and delay the spread of virus in lupine fields planted with virus-free seed, it is by no means certain that such borders will be effective every year or under different conditions. Consequently, other control methods should be sought. Although immunity is at present not available in commercially accepted lupines, it (or resistance) is available in certain perennial species of *Lupinus*. Recently, Bragdo (3) obtained seed from crosses between the perennial *L. polyphyllus* Lindl. and the commercial yellow lupine *L. luteus*. Although

the seeds failed to germinate, this partial success indicates that it may be possible to transfer the resistance from perennials into commercially accepted lupines. Variability within the genus *Lupinus* with respect to virus resistance of different species or lines has not been satisfactorily determined. Recently, a large collection of lupine material has been obtained from numerous areas throughout the world. This material may yield a more usable source of resistance or immunity to the virus.

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Potash Fertilization in a Mature Duncan Grapefruit Orchard

E. J. Deszyck and R. C. J. Koo*

INTRODUCTION

This paper is a final report on a series of plots first begun at the Florida Citrus Experiment Station in 1921 by Ruprecht (7). Early history of the plots is given by Sites (9). The original form of the experiment was not maintained in its entirety. Beginning in about 1930, poor tree condition, as a result of minor element deficiencies, made necessary the modification of the general fertilizer plan to include additional elements. The treatments were modified again in 1939, when the final general form of the experiment was initiated. The major change in potassium treatments in 1939 was to introduce a single plot on a no-potash treatment. The 3 and 10 percent levels of potash have been maintained without change since 1921. In 1956, the experiment was discontinued because of an invasion of the area by the burrowing nematode.

During the 35 years this series of plots was in operation, concepts of experimental design have been greatly changed. By present standards, the plots would be considered little more than a demonstration. However, a final report on these plots seems justified in order to put into the record a complete summary of the salient features of the latter part of the experiment's history and to present mineral analyses of leaf and fruit not heretofore reported.

EXPERIMENTAL PROCEDURE

The experimental orchard (9) was divided into six plots each containing 12 trees with a single guard row between plots. The Duncan grapefruit trees (70 acre) were grown on rough lemon rootstock in a well-drained Lakeland sand. During 1940-52, the trees were fertilized with a 3-6-X-3-1-0.5 mixture; since 1953, an 8-0-X-6-0.6-0 mixture was used. Potash in the mixture, either 0, 3, 5, or 10 percent was applied three times yearly in amounts shown in Table 1. The 3 and 10 percent plots were duplicated, while the check and 5 percent were single plots. Nitrogen was applied at approximately the same rate as that for the low level of potash, until 1954, when nitrogen was raised to 4.1 pounds per tree. With the exception of potash, all trees received the same treatment in keeping with good grove practices.

For mineral analysis approximately 100 spring-cycle leaves from non-fruiting twigs, and approximately 45 pounds of random fruit were collected from each plot. Samples were prepared and analyzed as described by Koo and Sites (4).

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TABLE 1.—Annual Potash Applications in Pounds Per Tree During 1940 to 1956.

K_2O Level	Year of Application		
	1940-49[a]	1950-53[b]	1954-56[b]
	K_2O—lb./tree/year		
Low	1.4	2.3	1.5
Medium	2.4	3.8	2.6
High	4.8	7.5	5.1
Check	0	0	0

[a]Average pounds of K_2O applied per year.
[b]Actual pounds of K_2O applied per year.

The following juice quality factors were measured (9) on sized fruit at regular intervals during each season: juice content, acidity, soluble solids, and vitamin C. Fruit size and percentage of U. S. Grade No. 1 were calculated from packinghouse data.

RESULTS

Mineral composition of leaves and fruit.—Seasonal changes in the potassium of spring-cycle leaves showed a general downward trend from June to February, 1954-55, with some exceptions (Table 2). These differences were more pronounced in leaves from trees receiving the greater applications of potash. Among sampling dates, largest change in potassium occurred from June to August. Afterwards the potassium gradually leveled off with the exception of that found in leaves from trees fertilized with the medium rate. The decrease in potassium with age of leaves is in general agreement with that reported by Brown and Chapman (1).

The potassium content of the leaves reflected the rate of potash fertilization (Table 3). In general, more potassium was found in leaves from trees fertilized with the high rates of potash than with the low rates. Also the variation in potassium percentages was first apparent in 1943. With years more potassium was found in the leaves during the earlier part of the experiment through 1945 than

TABLE 2.—Effect of Potash on the Seasonal Changes of Potassium in Spring-Cycle Duncan Grapefruit Leaves from June to February, 1954-55.

K_2O Level	Sampling Date				
	June 1	Aug. 1	Oct. 1	Dec. 1	Feb. 1
	K—Percent				
Check	.71	.47	.46	.47	.38
Low	1.85	1.38	1.11	1.18	1.12
Medium	2.39	1.72	1.71	1.87	1.55
High	2.66	2.18	2.07	1.93	1.86

during the following years with some exceptions. A positive relationship between the annual potash applied to the trees and the potassium content of spring-cycle leaves in July or August is shown in Figure 1. The calculated "t" (6.34) is highly significant.

A summary of the effect of potash applications on the potassium, calcium, magnesium, nitrogen, and phosphorus contents of spring-cycle leaves sampled during July or August appears in Table 4. Calcium and magnesium contents varied inversely as the potassium content of the leaves, as previously shown by Fudge (2), but nitrogen and phosphorus contents were not affected.

TABLE 3.—Effect of Potash on the Yearly Variation in the Potassium Content of Spring-Cycle Duncan Grapefruit Leaves in July or August for 7 Seasons.

K_2O Level	Year of Sampling						
	1943	1944	1945	1946	1949	1950	1954
	K—Percent						
Check	.91	1.19	1.21	.73	.55	.30	.57
Low	1.17	1.49	1.79	1.21	1.24	1.02	1.46
Medium	1.99	2.17	2.37	1.78	2.00	1.36	1.98
High	2.04	2.59	3.02	1.83	2.44	2.18	2.33

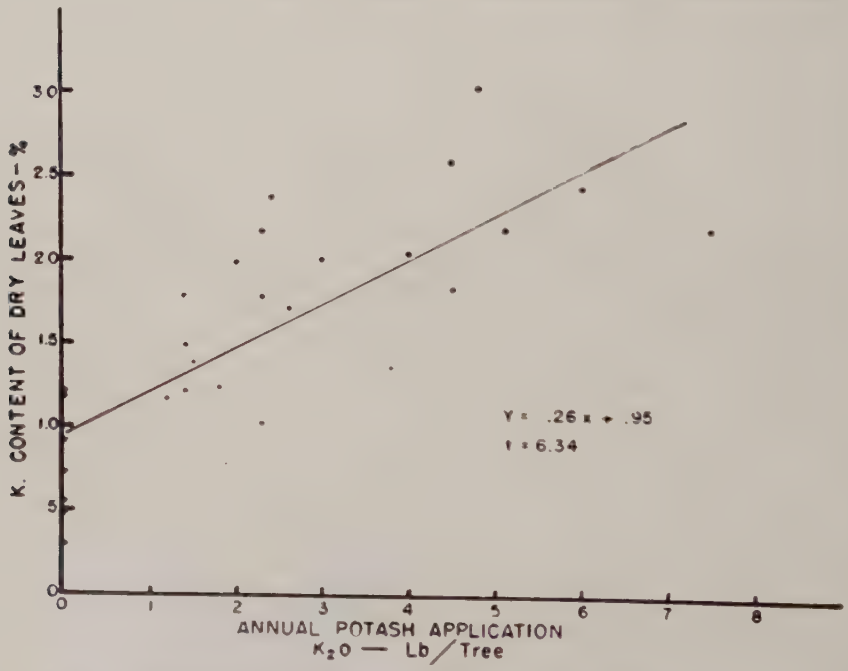

Figure 1.—Relationship between the annual potash application and the potassium content of spring-cycle Duncan grapefruit leaves in July or August during seven seasons.

The mineral composition of whole fruit is shown in Table 5. As with leaves, application of potash resulted in raised potassium content of the fruit. However, the range of potassium in the fruit is not as great as that of the corresponding leaves (Table 2). Calcium, nitrogen, and phosphorus contents varied inversely as the potassium, but magnesium content was not influenced.

Effect on fruit quality.—Results of internal fruit quality factors follow the same general trends as previously reported (5, 8, 9), and are summarized in Table 6. Potash fertilization resulted in increased soluble solids, acid, and vitamin C, but lowered ratio of soluble solids to acid, and juice percentage. A positive relationship exists between the potassium content of July or August leaves and the mean acid content of the fruit sampled throughout the entire season from September to March during the seven seasons (Fig. 2B). Since ratio (maturity index) varies inversely as the acid, an inverse relationship also exists between the potassium of the leaves and the ratio of the fruit as shown in Figure 2A. The calculated "t" values for the two regressions are highly significant.

Fruit size and U. S. Grade were influenced by potash fertilization, as shown in Table 6, although no consistent differences were apparent before 1950 (9). The percentage of U. S. Grade No. 1 fruit was the highest on the no-potash program and the lowest on the high level

TABLE 4.—Effect of Potash on the Mineral Composition of Spring-Cycle Duncan Grapefruit Leaves in July or August.[a]

K_2O Level	Mineral Element				
	K	Ca	Mg	N	P
			Percent		
Check	.78	5.35	.43	2.37	.156
Low	1.34	5.04	.38	2.34	.158
Medium	1.95	4.27	.30	2.31	.147
High	2.35	4.10	.30	2.35	.154

[a]Each figure is the mean of 7 years' data.

TABLE 5.—Effect of Potash on the Mineral Composition of Duncan Grapefruit During 1954-55.[a]

K_2O Level	Mineral Element				
	K	Ca	Mg	N	P
			Percent		
Check	.84	.34	.13	1.30	.170
Low	1.32	.30	.12	1.19	.154
Medium	1.51	.27	.12	1.16	.150
High	1.73	.26	.12	1.09	.146

[a]Each figure is the mean of random fruit samples taken November 10, 1954, January 3 and March 3, 1955, on a dry weight basis.

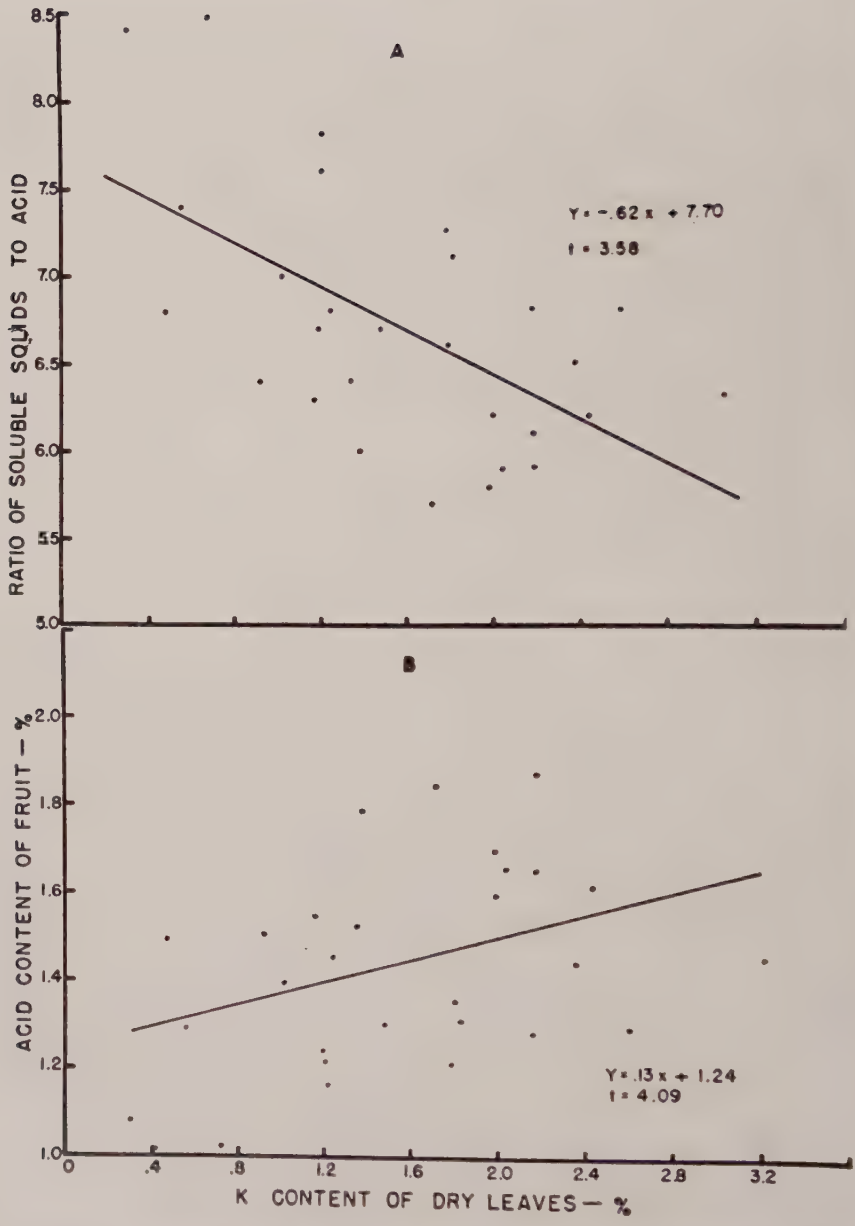

Figure 2. Relationships between the potassium content of spring-cycle Duncan grapefruit leaves in July or August and (A) ratio of soluble solids to acid, and (B) acid content of the fruit.

potash fertilization. The low pack-out was due chiefly to coarse rind. Average fruit diameter varied directly as the amount of potash applied. The difference between diameters of fruit from plots on the high potash level and that on the no-supplemental potash amounted to 0.18 inches, or approximately one commercial size. Results are similar to those reported for oranges (5, 10).

Effect on pre-harvest fruit drop and yield.—The effect of potash fertilization on pre-harvest fruit drop and yield of Duncan grapefruit is summarized in Table 7. Potash fertilization resulted in a marked reduction in fruit drop and an increase in yield. Because of inadequate replication, the significance of yield differences among the three higher potash levels remains in doubt.

TABLE 6.—Effect of Potash Fertilization on Internal and External Quality of Duncan Grapefruit.[a]

K_2O Level	Fruit Quality Factors						
	Soluble Solids %	Acid %	Juice %	Vitamin C mg/ 100 ml.	Ratio	U.S. Grade No. 1[b] %	Diameter[b] in.
Check	9.5	1.32	46.6	36.2	7.3	49.3	4.13
Low	9.9	1.51	44.3	38.5	6.7	45.3	4.20
Medium	9.8	1.58	44.7	39.7	6.3	43.7	4.26
High	10.1	1.61	42.9	41.1	6.3	41.4	4.31

[a]Mean values of samples taken from 1940 to 1956.
[b]Mean values taken at harvest during 1945 to 1956.

TABLE 7.—Effect of Potash on Pre-Harvest Fruit Drop and Yield of Duncan Grapefruit for 16 Years.

K_2O Level	Fruit Drop[a] No./tree/year	Average Production (lb./tree/year)			
		1940-46	1947-50	1951-53	1954-56
Check	206	830	295	246	375
Low	88	553	538	789	741
Medium	74	914	646	1013	846
High	75	639	588	974	816

[a]Average fruit drop from August to February for 8 seasons.

DISCUSSION

Duncan grapefruit trees previously fertilized heavily with potash may require several years without potash addition to show deficiency symptoms in the field. Thus under the conditions of this experiment trees without supplemental potash produced heavily and contained sufficient potassium in the leaves until the seventh year. First heavy pre-harvest fruit drop occurred during the summer of 1945 when

the leaves contained 1.21 percent potassium, also a substantial reduction in yield was first apparent during the 1946-47 season, and continued to the end of the experiment. During this period of low yield from trees without added potash, the spring-cycle leaves in the summer contained 0.73 percent potassium or less.

The reasons for the high yield and apparently adequate potassium in the leaves from trees without added potash until 1946 are not evident at this time. Even so, several factors may be mentioned: (a) The potassium reserves in the trees were probably high since potash applications in this plot were high in previous years. (b) Low nitrogen was applied through 1949, amounting to approximately 100 pounds per acre. On such a program the potassium content in the leaves is likely to be higher than in leaves from trees supplied with higher levels of nitrogen (5). It is believed that on a higher nitrogen fertilization, potassium deficiency symptoms would have been apparent earlier. (c) Pre-harvest fruit drop continued to supply some potash to the trees in the no-potash plots. Removal of this fruit was first begun during the 1945-46 season. Perhaps removal in previous seasons also would have been more satisfactory. (d) In the deep, sandy soil, underground water movement from potash fertilized areas may be instrumental in supplying potash to the trees on the no-potash program. Single buffer rows may not be adequate under these conditions. The plot design may be inadequate since each plot consisted of three rows of four trees each. More trees in each plot with a double guard row would be more satisfactory in potash studies on citrus trees grown under these conditions (3). (e) Rough lemon rootstock on such soils usually has extensive feeder roots extending deeply into the soil.

The critical level of leaf potassium necessary to prevent yield reduction in Duncan grapefruit may be higher than in oranges. According to Reuther and Smith (6), the critical level in orange leaves is 0.6 percent potassium or less, with no sharp reduction in yield until the potassium content falls below 0.4 percent. Chapman and Brown (1) under California conditions indicate that orange leaves below 0.35 percent potassium may be deficient and chances of yield response to potash fertilization are good under such conditions.

The potassium levels in leaves and fruit were directly related to the amount of potash applied to the trees. Leaves from trees receiving none to 7.5 pounds potash contained a wide range of potassium (0.30-3.02 percent), but fruit from the same trees contained a narrow range (0.84-1.71 percent). The results indicate that further studies may make it feasible to use the potassium content of leaves or fruit as a guide for recommending potash fertilization.

Higher potash fertilization usually delays maturity of Duncan grapefruit. Under the Florida maturity standards fruit must attain minimum juice, soluble solids, and ratio of soluble solids to acid before harvest. The juice requirements are high through October 15 of each season. Increasing the potash levels in the fertilizer results in a lowered juice percentage of the fruit. This may be an indirect effect since fruit grown on a high potash level usually contains a thick rind. Low juice content may be a factor in delaying harvest, especially in the early season. Acidity is raised consistently with increases in the potash levels in the fertilizer. Since ratio is influenced by the acid

content, small changes in this factor result in substantial changes in the ratio. For example, fruit from deficient trees attained the minimum ratio of 7.0 in October during two-thirds of the seasons, but fruit from trees treated with the varied rates of potash attained this ratio only one-fifth and one-tenth of the seasons for the two lower rates and the high rate, respectively.

Grapefruit is naturally high in acidity and may not be highly acceptable to the consumer. Even though arsenical sprays are used on grapefruit trees to lower acidity, the supply of fruit with low acid and high ratio is inadequate to meet the demands of the fresh fruit market or processing plants during most of the season. The processor desires fruit of high ratio in order to manufacture a concentrate juice that is a palatable and a desirable product without the addition of sugar. Raw grapefruit for processing into concentrate must meet higher quality standards of soluble solids and ratio than is required for the fresh fruit market. Grapefruit from trees grown on a high potash level contains high acidity and low ratio, and thus cannot always meet the high standards required by processors of concentrate juice, but fruit from trees fertilized with low amounts may be more desirable from this standpoint.

SUMMARY

Results of mineral analysis (potassium, calcium, magnesium, nitrogen, and phosphorus) of leaves and whole fruit from mature Duncan grapefruit trees fertilized with varied rates of potash since 1939 are presented. The potassium content of these tissues increased with soil applications of potash. In general, the potassium content of the leaves varied from year to year and decreased with age of the leaf. Leaves from trees without supplemental potash attained a low level of potassium beginning with the summer of 1946, or seven years after the start of the no-potash treatment.

Potash fertilization resulted in higher acidity, soluble solids, and vitamin C, but lower juice percentage and ratio of soluble solids to acid in Duncan grapefruit. A positive relationship existed between the potassium content of the spring-cycle leaves and the acidity of the fruit. Consequently, an inverse relationship between amount of this element and the ratio of the fruit was also present. Size and yield of the fruit were raised with potash fertilization but the percentage of fruit of U. S. Grade No. 1 and pre-harvest drop were lowered.

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BANQUET AND BUSINESS MEETING

The annual business meeting of the Society was held in the Student Service Center on the campus of the University of Florida immediately following Dr. Firman E. Bear's address "All Flesh is Grass" which was a part of the program of the annual banquet. Provost Willard M. Fifield acted as master of ceremonies. Dr. Bear's address is published in full in this volume.

The meeting was called to order by President Darrell E. McCloud and the report of the Secretary-treasurer on membership, finances and publication constituted the first matter of business. As usual, the reading of the minutes of the previous meeting was dispensed with in view of the completeness of the published record in Proceedings Volume 16 (1956).

MEMBERSHIP

The status of membership as of the close of the calendar year is shown in the following table that lists the members in three different categories, annual, sustaining and honorary life, according to geographical distribution. This procedure has been followed for the past two years, 1956 and 1957. It is a matter of considerable interest that a total of 25 new members were added to the rolls of the Society in the course of the annual meetings.

GEOGRAPHICAL DISTRIBUTION OF MEMBERSHIP

	Annual		Sustaining		Honorary Life		Total	
	6/1/57	4/1/58	6/1/57	4/1/58	6/1/57	4/1/58	6/1/57	4/1/58
Florida	550	568	97	102	1	1	648	671
U. S. (other than Florida	171	168	47	43	7	8	225	219
Caribbean	99	109	7	6	–	–	106	115
Foreign	40	37	8	10	1	1	49	48
	860	882	159	161	9	10	1028	1053

REPORT OF THE TREASURER

Statement of Receipts and Disbursements
January 1, 1957 thru Dec. 31, 1957

Cash in bank 12/31/56		
Everglades Federal Sav. & Loan Co.	$3,882.65	
Florida National Bank	479.16	
		$4,361.81

RECEIPTS:

Regular dues collected	966.00	
Sustaining dues collected	2,875.00	
Proceedings sold	93.00	
Donations (by members)	113.25	
Postage refunds	.70	
Registrations at annual meetings	117.00	
Interest (Everglades F.S.&L. Co.—acct. closed)	77.67	
		$4,242.62
Total monies to be accounted for		$8,604.43

DISBURSEMENTS:

Office Supplies	82.99	
Postage	300.00	
Binding office Proceedings	13.00	
Printing—Volume 16	4,379.33	
Secretarial assistance	600.00	
Bank charges	.75	
Expenses annual meeting 1956— 19.95		
1957— 125.00	144.95	
		5,521.02
Cash in bank 12/31/57		
Florida National Bank		3,083.41
Total monies accounted for		$8,604.43

It is a pleasure to report that the response to the suggestion of a free-will offering that might be sent along with the annual dues was a very generous one since contributions were received from a total of 60, or 24.1 per cent of all members paying dues during that period immediately prior to the meeting in Gainesville. These varied in amounts from 50c to $8.00. The total amount gratuitously presented in this way was $113.25 up to the end of the year. Since that time we have received $17.00 from 12 members.

PUBLICATION

The fact that Proceedings Volume 16, with a total of 378 pages and the largest yet published, was in the mail well in advance of the annual meeting set a new record of which President McCloud should be proud and all members of the Society grateful. As a matter of fact, it was the cost of this volume (well over $3.00 each) which suggested the call for free will contributions from the annual members. The size of the volume also took it into a higher postal bracket with the result that the mailing of each volume cost 50 per cent more than any of the previous ones—at a total of about $60.00 for the whole edition by the time all are sent out.

Fifteen hundred and twenty-seven copies of Proceedings Volume 16 were published and 1294 were distributed by the close of the year.

REPORT OF RESOLUTIONS COMMITTEE

The Resolution of Sympathy read by the Secretary told of the loss by death of ten members of the Society during the year. The reading was followed by a brief period of silence at the request of the President. This resolution is published in full on page ..... of this volume.

NOMINATION AND ELECTION OF AN HONORARY LIFETIME MEMBER

Since the 10th birthday of the Society (1950) when that number of outstanding soil and plant scientists from all over the world were elected to honorary lifetime membership in the Society, it has become the custom to elect a new member to this honor at any time a vacancy in the group occurs.

Last year two memberships were vacated by death as reported in Proceedings Volume 16. To one of these Dean Emeritus Dr. H. H. Hume was nominated and elected in an interim manner by the Executive Committee. His acceptance was reported in that volume.

As an important part of the business meeting for the current year Dr. Firman E. Bear's name was placed in nomination by the President and he was unanimously elected by voice vote.

The Society is indeed honored to have two such distinguished scientists in the fields of horticulture and soils, respectively, each world-renowned in his own right, accept our modest though heart-felt offers of recognition and tribute.

REPORT OF NOMINATING COMMITTEE AND ELECTION OF OFFICERS

The Nominating Committee appointed by President McCloud during the first day of the meetings consisted of Dr. Earl S. Horner, Dr. L. C. Hammond and Dr. Earl Rodgers, with the latter acting as Chairman. Only one position requires action each year, that of Vice-President. The Vice-President automatically ascends to President by constitutional provision.

Upon call by the president for the committee's report, Dr. Rodgers offered as their unanimous choice Dr. P. H. Senn, Head, Department of Agronomy, Teaching Division, College of Agriculture. It was then moved that the nominations be closed. The motion was seconded and carried unanimously whereupon the secretary was instructed by the president to cast a unanimous ballot for Dr. Senn. Immediately, the election was concluded and Dr. McCloud turned the gavel over to Dr. G. D. Thornton, Vice-President of the past year, as the incoming President.

Dr. Thornton briefly reviewed the fact that it has become customary for the newly elected vice-president of the Society to automatically become chairman of the program committee for the coming year. He also reviewed the manner in which the programs have been developed during the past few years by contacting Experiment Station

workers largely through the heads of pertinent departments at the main Station in Gainesville and of Branch Stations and Field Laboratories over the State. It is expected that each will contact his own research workers as well as industrial workers in his area of work for potential program material each year.

There being no other business to come before the meeting it was declared adjourned by the Chairman at 10:15 P.M. after a call by President Thornton for a brief meeting of the Executive Committee to be held the following day at a time and place to be announced.

MEETING OF THE EXECUTIVE COMMITTEE

The meeting of the Committee was called to order by President Thornton with all members in attendance. The meeting convened at 10:30 A.M. in Room 209, Dan McCarty Hall on the University of Florida Campus.

The first matter of business was the selection of a Secretary-Treasurer. This was done by appointing R. V. Allison to serve in this capacity for another year.

Following a general discussion of special themes as well as time and place for the next meeting it was decided that special emphasis would be given to program material of particular interest to our good friends and members in Latin America. With this idea in mind it was decided to explore the possibility of holding the next annual meeting in South Florida, probably in the Miami area, but no definite decision was taken in this regard. Timing the meeting with that of the Caribbean Conferences held on the Campus of the University of Florida each year early in December was also discussed as a very desirable arrangement.

A considerable amount of discussion also was given to the need for a reworking of the constitution of the Society in view of the recent name change and several other limitations that are quite obvious in its present form, with the result that the President was authorized to appoint a committee for this purpose as early in the year as possible.

There being no other business to come before the meeting, adjournment was declared by the Chairman at 12 o'clock noon.

RESOLUTION OF SYMPATHY

WHEREAS, death has taken from our rolls during the year the following esteemed members of the Society whose sincere and constructive interest in all aspects of the work will make their absence keenly felt for a long time to come,

NOW, THEREFORE, BE IT RESOLVED, that this expression of sorrow over this great loss and of sympathy to the immediate families of the deceased be spread upon the records of this Society and a copy of same be sent to the closest member of the family of each.

Dr. Ira Allison
Springfield, Missouri

H. I. Cohn
West Palm Beach

Boyd H. Hill
St. Petersburg

Robert L. Pendleton
Bangkok, Thailand and
Baltimore, Md.

Dr. J. K. Plummer
Atlanta, Ga.

Fritz Stein
Belle Glade

R. B. Trueman
Jacksonville

Norman Tuckett
Minneola

Capt. G. C. Westervelt
Indian Town

Carlos Wimmer
Pueblo, Mexico

DARRELL E. MCCLOUD

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1957—Retired

D. E. McCloud	President
G. D. Thornton	Vice-President
R. W. Ruprecht	Past President
R. V. Allison	Secretary-Treasurer

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1957

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